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TAMPERE UNIVERSITY OF TECHNOLOGY

VILLE SÄLLINEN

SUPERHEATER CORROSION MANAGEMENT IN BIOFUEL BOILERS

Master of Science thesis

Examiner: professor Risto Raiko
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Uusiutuvia polttoaineita, kuten biopolttoaineita ja kierrätyspolttoaineita käyttävissä voimalaitoksissa tulistimien korroosio aiheuttaa suurempia ongelmia kuin voimalaitoksissa, jotka käyttävät fossiilisia polttoaineita. Ongelmat johtuvat uusien polttoaineiden koostumuksesta. Koostumus on verrattaen paljon klooria mutta vähän rikkiä sisältävä. Metson kehittämä ratkaisu korroosio-ongelman hallintaan on nimeltään Metso Fuel Diet. Tämä tuote koostuu Metso Corrored analysaattorista, Metso DNA Corrosion Manager -sovelluksesta, korroosioon liittyvästä asiantuntemuksesta ja mahdollisesta lisäainesyöttöjärjestelmästä. Corrored analysaattoria käytetään mittaamaan savukaasujen kemiallista koostumusta. DNA Corrosion Manager –sovellus hyödyntää analysaattorin mittaustuloksia. Tämä sovellus koostuu informaationhallintatoiminnoista ja prosessin säätötoiminnoista.
Corrored analysaattorilla mitataan savukaasujen rikki- ja klooripitoisuuksia tulistinalueella. Näiden pitoisuuksien sekä tulistinalueen lämpötilan perusteella voidaan laskea arvio korroosioriskin suuruudesta. Laskenta tarjoaa tämän jälkeen työkalut korroosion seurantaan ja korroosion hallinnan suunnitteluun. Tämän lisäksi on kehitetty automaatiojärjestelmän säätöjä, joilla pyritään pitämään korroosioriski mahdollisimman pienenä joko säätämällä lisäainesyöttöä, polttoaineseosta tai tulistinalueen lämpötilaa.
Tässä työssä esitellään ensin tulistimien korroosion kemiallinen toimintamekanismi. Tämän jälkeen esitellään Metso DNA Corrosion Manager -korroosion hallintasovellus. Hallintasovelluksen puolella työn pääpaino on informaationhallintatoimintojen kehittämisessä. Lisäksi työssä on panostettu erityisesti käyttäjäystävällisen käyttöliittymän suunnitteluun. Työssä on esitelty myös kehitysprojektin yhteydessä toteutettu pilottiprojekti Kuopion Energian Haapaniemi 3 kattilalaitokselle.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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Power plants using renewable fuels like biofuels or recycled fuel suffer from problems caused by corrosion in superheaters more than powerplants using fossil fuels. These problems are caused by chemical composition of renewable fuels. The composition is high in chlorine and low in sulphur. Solution for these corrosion problems developed by Metso is called Metso Fuel Diet. This solution consists of Metso Corrored analyzer, Metso DNA Corrosion Manager application, corrosion know-how and optional additive feed system. The Corrored analyzer measures the chemical composition of flue gases and Metso DNA Corrosion Manager application uses these analyzer results. This application consists of information management part and control part in automation system.

The Corrored analyzer is used to measure sulfur and chlorine contents of flue gas at the superheater area of the furnace. With this information and information about temperatures at the superheater area a corrosion risk value is calculated. Information system offers then tools to monitor corrosion and to plan corrosion management in the plant. Plant controls in automation system were also developed to control corrosion by additive feed, by fuel diet or by lowering the temperature at the superheaters.

In this thesis work is first described the chemical process that causes the corrosion in the superheaters. After this, Metso DNA Corrosion Manager product is described. In this thesis work, the main focus is in information management side. A lot of focus is also given to the development of user friendly user interface. There is also a description of the pilot project made during this thesis work to Kuopion Energia Haapaniemi 3 boiler plant.

PREFACE

This Master of Science thesis was done at Metso Automation during the year 2013. The process of making this thesis has given me a significant amount of experience and knowledge about power plants, process automation and information management.

I wish to thank my examiner Professor Risto Raiko for all the support during this work.

I want to give my thanks to my supervisors Maria Nurmoranta and Markku Rintala for all of the guidance during this thesis work. I would also like to thank Jaani Silvennoinen and Joni Maunula from Metso Power for all their support and technical guidance regarding the corrosion in boilers. I want to give my thanks also for Matts Almark and Petri Köykkä for their support in the area of process control.

I would like to thank my family for all the support they have given me over the years and for encouraging me in my studies. I would also like to thank all my friends and more recently my co-workers for the refreshing and inspiring social environment you create.

CONTENTS

ABBREVIATIONS

DNA	Automation platform product of Metso Automation
PVC	Polyvinyl chlorine
SRF	Solid recycled fuel
S/Cl	Sulfur to chlorine molar ratio
PID	Proportional-integral-derivative
CEMS	Continuous emission monitoring system
SQL	Structured query language
UI	User interface
DCS	Distributed control system
C#	C sharp programming language

1 INTRODUCTION

Renewable energy is widely regarded as the energy of the future. Along with other renewable energy sources, biomass fuel and recycled fuel combustion solutions will play an important part in the process of getting rid of fossil fuels. This means that biomass fuel and recycled fuel will be used in bigger scale, which leads to demand of higher process temperatures. A need to get rid of supporting fossil fuels in biomass fuel and recycled fuel boilers is also expected to grow.

Higher process temperatures and higher contents of biomass or recycled fuel lead to a growing risk of corrosion in boiler, especially in the region of superheaters. High corrosion rate leads to economical losses. Superheater failures always lead to boiler shutdown and maintenance break to replace the superheater tubing. This of course means loss of profits and costs in maintenance.

Corrosion can be controlled with fuel mixture control and additive feeds, or by operating the boiler with more secure temperatures. Good and effective control is depending on measurements of the controlled process. In the case of superheater corrosion control this has been made possible with Metso Corrored analyzer.

This thesis concentrates on the development of information and control application to monitor and control corrosion with Metso Corrored analyzer. Main focus is in the information management part. The goal is to create informative and user friendly application, which will be used by plant operators and plant management. Application is developed with feedback from pilot case customers.

Special focus will be in the development of the user interface of the application. Common problem is the integration of applications in the everyday operation of plants. Operators tend to maintain previously learned ways of doing things and operate the plant in the way that is the easiest but not the most effective. The goal is to develop a user interface that is both informative and addictive, so that struggles to integrate the application to operators' daily routines will be less troublesome. Plant operator should monitor corrosion constantly and control the process accordingly.

Some focus will also be in the future development of the corrosion control application and also on the future development of Metso user interfaces. The analyzer technology is new and all possible utilizations may not yet have been thought of. The development of the user interface may provide results that can be utilized in other Metso applications.

2 CORROSION IN SUPERHEATERS

This thesis work deals with corrosion of superheaters in biofuel and recycled fuel boilers. Main focus is on the development of an info and control application based on a new measurement technique developed by Metso. To understand the functions of this application we must first understand the physical and chemical basis of high temperature superheater corrosion in biofuel and recycled fuel boilers.

2.1 Corrosion of metals

Corrosion means the oxidization process of metals. The reaction involves the metal and some oxidizing substance with more positive standard reduction potential than the reacting metal. In typical cases the oxidizing substance is oxygen. Usually this reaction causes the metal to lose its structural integrity and for this reason it is highly unwanted phenomena. The oxide produced in the reaction with oxygen creates a layer in the surface of the metal. This layer can act as a protective shield against further corrosion, although surrounding conditions affect the structure and effectiveness of the oxide layer. In highly corrosive conditions the layer does not provide protection against further corrosion and this can cause serious problems. (Zumdahl 2005)

Temperature affects the corrosive potential of different conditions. High temperature corrosion means usually corrosion in hot conditions with no moisture present. High temperature increases reaction rates, but it can also cause corrosion in other ways. When the conditions include compounds which could melt to the metal surface we face completely different kind of corrosion problems. Molten phase acts as a more effective electrolyte for ionic charges to move. Chemical reactions are also faster in molten phase. (Tunturi 1988, Salmenoja 2000)

2.2 Fluidized bed boilers

Fluidized bed combustion has become an important technology in the fight against carbon dioxide emissions. This technology is suitable for low quality fuels such as most biomass fuels and municipal waste fuels. Other benefit of fluidized bed combustion is the possibility to use wide range of fuels in the same boiler. Fluidized bed boilers are also tolerant to rapid changes in the fuel quality. The fluidized bed is created by blowing part of combustion air upwards from nozzles at the boiler floor through a layer of solid particles. Heat is reserved in these particles creating a more stable combustion environment.

A bubbling fluidized bed is created when the air is blown into the boiler with high enough velocity to produce a bubbling bed of solid particles. The velocity of the air must at the same time be low enough to prevent the particles from escaping the boiler.

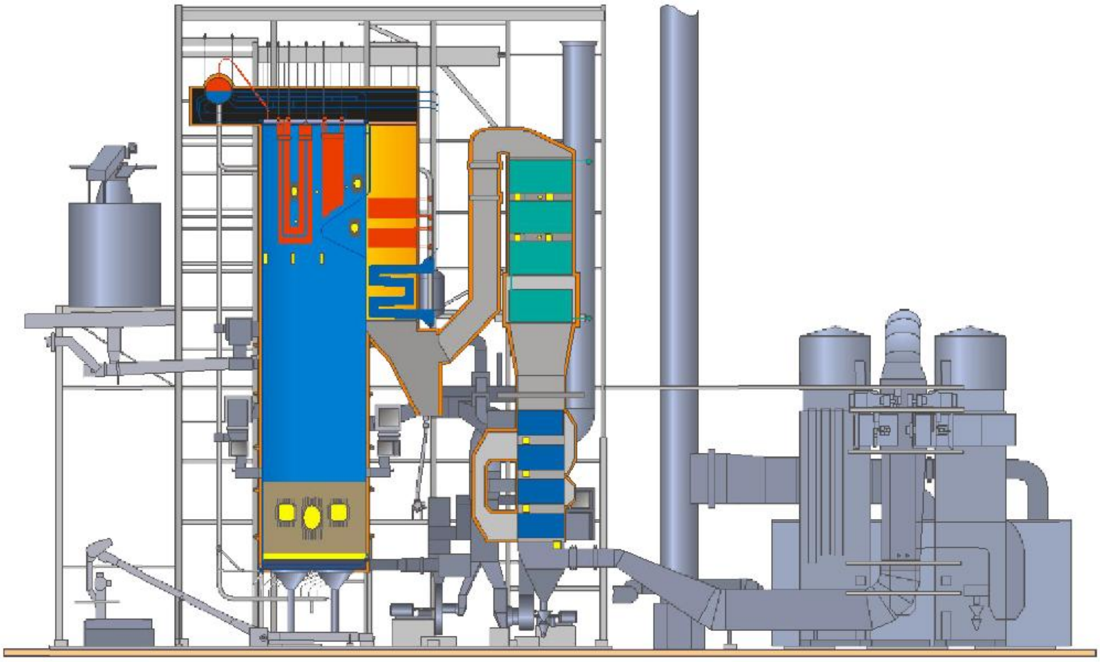

Figure 2.1: Profile of Metso HYBEX bubbling fluidized bed boiler

A circulated fluidized bed is created with an air velocity that allows the particles to escape with the flue gas. This means that a system is needed to separate the escaped particles from the flue gas flow and to return them back to the boiler. This can be done with a cyclone separator. One important difference between bubbling and circulated bed boiler is the temperature profile of the boilers. Circulated bed provides a stable temperature profile for the whole boiler, whereas the bubbling bed creates a hotter area in the bottom of the boiler. (Raiko et al. 2002)

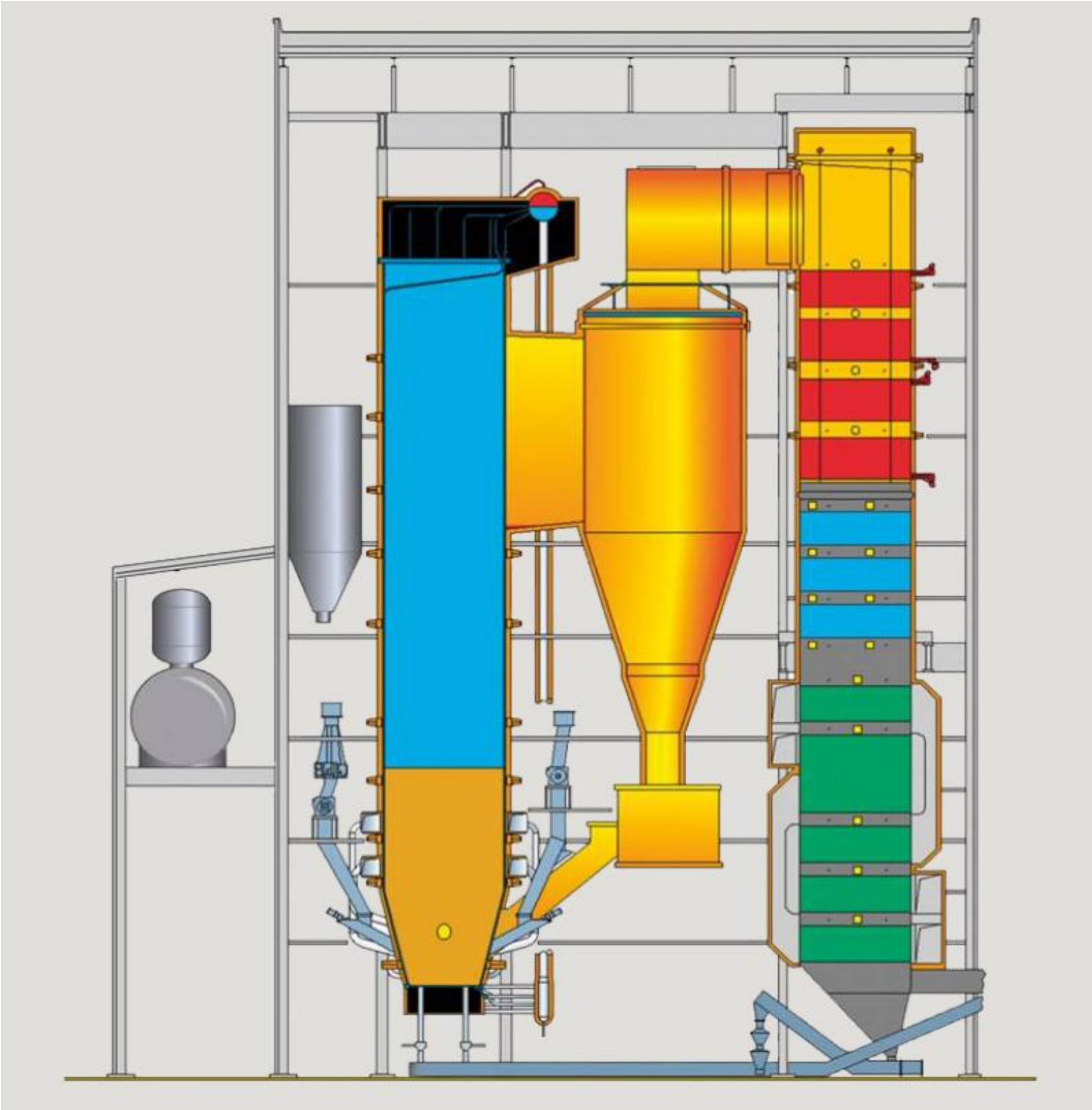

Figure 2.2: Profile of Metso CYMIC circulated fluidized bed boiler

2.3 Biomass fuel and recycled fuel

Biofuels are renewable combustibles used in energy production. The term biomass fuel is used for solid biofuels. Biomass is formed by vegetation via photosynthesis process. Biomass is regarded as renewable energy, so it is relatively young fuel compared to fossil fuels. The global carbon dioxide burden is not increased when combusting renewable fuels. Ages of biomasses vary from annually harvested fuel sources to wood that can be over 100 years old. Peat may be up to 1000 years old, so its status as a renewable energy source is controversial.

Biomass fuels have usually lower carbon content and heating values than fossil fuels. Typically biomasses have low contents of sulfur and sodium, but relatively high contents of chlorine and potassium. Younger biomasses like agricultural fuels have typically higher chlorine and alkali contents than wood-based fuels. Combustion of biomasses is often difficult because of high amount of moisture in the fuel. This is why a fluidized bed combustion technology is commonly used for biomass combustion. (Salmenoja 2000, Silvennoinen et al.)

Recycled fuel is of highly unpredictable nature. The composition of recycled fuel varies greatly by location and culture. The variance in the quality of the fuel flown to the boiler is also large. Many kinds of impurities may be found in recycled fuel and some of these impurities may cause serious corrosion risks. Impurities and heterogeneous nature of the fuel also causes problems for combustion, so again fluidized bed technology can be used to give stability to the combustion process. Polyvinyl chloride (PVC) plastics and rubbers are a common source of chlorine in recycled fuel boilers. Heavy metal and alkali metal impurities are also often present, and together with chlorine they produce high corrosion risk. In figure 2.3 recycled fuels are viewed as SRF (solid recycled fuel) and as recycled wood. (Lai 2007)

	Elements of concern	Example fuels	Challenge rate
Wood		Spruce bark, forest residuals	2
Wood +	Cl, alkali, ash	Eucalyptus bark, willow	4
Agro	Cl, alkali, P, Si, N	Straw, hulls	7
Recycled wood	Cl, alkali, heavy metals	Recycled wood	7
SRF	Cl, alkali, heavy metals, ash	Solid recovered fuels	8
Fossil		Bituminous coal	2
Fossil +	Ash	Coal washing reject, petroleum coke	3

Figure 2.3: Metso fuel ranking (Silvennoinen et al. 2013)

2.4 Corrosion effect of chlorine and alkali compounds

Recent studies suggest that conditions where temperature is high and chlorine and alkali metals are present produce a highly corrosive environment. This kind of environment is often produced when burning biomass or recycled fuel in fluidized bed boilers. Chlorine and alkali metals form compounds that form low-melting and corrosive deposits in boiler tubing, especially in the superheaters.

Figure 2.4: Examples of corrosion damage in superheater tubing (Silvennoinen et al. 2013)

The combustion of fuels with high chlorine and alkali content releases these highly volatile materials to form compounds. Chlorine and alkali metals react in suitable conditions to form alkali-chlorides. These compounds can form low-melting deposits in the superheaters via direct condensation or thermophoresis. These alkali chlorides move in the deposit to the metal surface. At the metal surface these alkali chlorides induce corrosion and form $FeCl_2$ as a corrosion product. (Frandzen 2011, Silvennoinen et al., Discussion with Jaani Silvennoinen)

The melting of the deposit does not take place in a specific temperature, but in a temperature range which is dependent on the composition of the deposition. The lowest temperature in the range could be significantly lower than any of the melting temperatures of the components in the deposit. This makes it difficult to predict the properties of the deposit in different temperatures. (Klarin 2009)

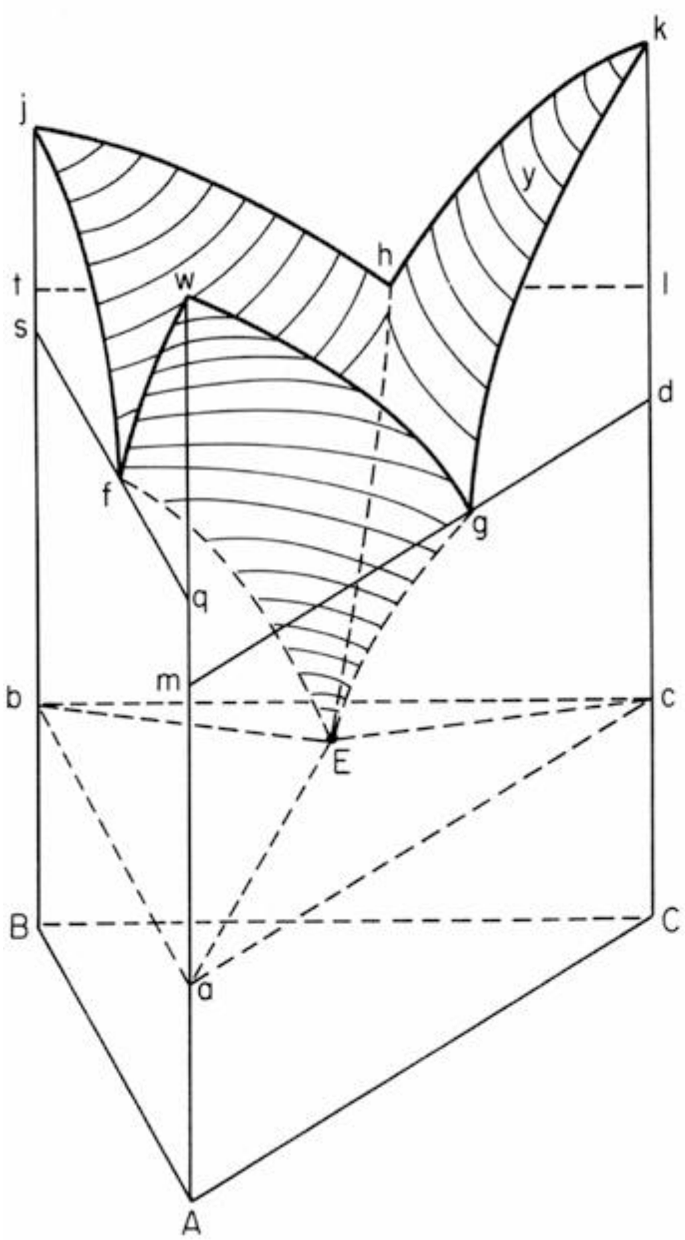

Figure 2.4: Effect of multi component mixture on melting temperature (Klarin 2009)

2.5 Effect of sulfur

The increase of available sulfur oxides in the flue gas will increase the rate in which the sulfation of alkali chlorides occur in the flue gas, thus preventing alkali chlorides from depositing in the superheaters. The sulfation reaction can include either SO_2 or SO_3, but the reaction rate with SO_3 is considerably higher. The same sulfation reaction can happen also in the deposits. For this reason a sulfur-to-chlorine ratio of 2.0 in the fuel is suggested to be needed to prevent serious corrosion problems by alkali chlorides in the deposits. A ratio of 4.0 is suggested to be enough to make corrosion rates via alkali chlorides negligible. (Salmenoja 2000, Silvennoinen 2011)

While the formation of sulfur oxides is beneficial in reducing corrosion in superheaters, it is unwanted in the environmental point of view. Sulfur oxide emissions are harmful for health and environment, causing respiratory diseases and acidic rains. These emissions spread to wide regions with airflows. For these reasons the targets regarding sulfur dioxides have been to reduce them by any means. (Raiko et al. 2002)

2.6 Corrosion Key Figures

As discussed earlier, sulfur to chlorine molar ratio (S/Cl-ratio) is a good measurable corrosion indicator. The higher the sulfur level is compared to chlorine level the more it reduces the amount alkali chlorides in the deposits and thereby reduces corrosion. The ratio level of 4.0 is suggested to be enough to reduce alkali chloride induced corrosion almost completely. A rate of 2.0 is also suggested to be enough to reduce corrosion to insignificant level. At lower levels corrosion may cause problems. (Salmenoja 2000) The S/Cl ratio is not the only affecting measure for corrosion. For this reason other calculated values are designed to take into account other values affecting corrosion.

Better estimate of corrosion is achieved when taking into account also temperatures at the superheater area. Another factor affecting corrosion is the superheater material. Materials with properties to reduce corrosion tend to be more expensive, so for cost optimization reasons to best available material is seldom used. A corrosion risk value can be estimated when taking into account all these measures. In this thesis work a corrosion risk index is a 0-100 value based on calculation provided by Metso Power know-how.

Another calculated value provided by Metso Power know-how and based on the same measures is corrosion rate that can be quantified as mm/a value of corrosion in the superheater material. This estimated value gives a lot of opportunities to analyze superheater corrosion. A cumulative corrosion value may be created to quantify the total material thickness loss caused by corrosion. With the cumulative corrosion value an estimate of remaining material thickness may also be calculated. Another value that can be easily calculated with corrosion rate and remaining material thickness value is the remaining lifetime of the superheater. (Almark et al. 2013)

2.7 Problems and economical losses caused by corrosion

Rapid corrosion of superheater elements is of course unwanted. If no way to measure the corrosion is available, corrosion rate is not known. The unpredictable nature of chlorine induced corrosion causes unpredictable shutdowns of the boiler. These unpredictable shutdowns are followed by unplanned maintenance breaks. Economical benefits are achieved if maintenance breaks are fever and if they can be planned and scheduled in advance.

From the point of view of the plant supplier, economical losses are caused by corrosion because problems appear during guarantee period. The suppliers' reputation and competitiveness in new sales cases is also dependant on success in previous projects. For this reason problems during guarantee periods are unwanted. (Almark et al. 2012)

To reduce corrosion problems plant operators and plant management have some options. A secondary fuel may be used to control furnace atmosphere to reduce corrosion. This fuel is often more expensive and is often used in unnecessarily high quantities because the effect it has on corrosion is difficult to measure. This causes unnecessary expenses for the plant owner.

Other way to reduce corrosion is to operate the plant with lower temperatures. This means that the efficiency of the plant is at the same time reduced. Reduced efficiency means of course reduce in profits for the plant owner. In cases where corrosion cannot be measured exactly this kind of control method is difficult to execute correctly. (Discussion, Jaani Silvennoinen)

3 CORROSION CONTROL IN BOILER ENVIRONMENT

Corrosion problems are not new to boilers. Ways to reduce corrosion have been developed and in this part of this thesis these ways to control corrosion is discussed. Traditional corrosion control actions are discussed first. Later some new ways to control corrosion developed by Metso are introduced.

3.1 Boiler control

Efficient and smooth operation of the boiler is required from the control functions controlling the boiler. However there are many dynamic features affecting the controls of the boiler. This makes the controlling of the boiler challenging. Affecting features are at variety in fuel quality and fuel feed rate, changes in power output demand and changes in combustion conditions.

The challenging control environment requires advanced control functions. Metso's solution in combustion control is based on fyzzy logics control. Fyzzy logics mean control based on linguistic control rules that can be configured to follow typical human made operator actions in different situations. These control actions are more understandable to operators and offer clearer interface between controls and operators. (Metso Automation, 2010)

3.2 Traditional corrosion control

Boiler design has been the only way to control superheater corrosion conventionally. The goal has been to prevent highest possible temperatures in the tubing, and on the other hand to use more corrosion resistant materials in areas where temperatures are the highest. These options cause some economical losses, because better materials are usually more expensive, and the best possible steam values are not reached.

The ideal way to arrange superheaters is counter-currently. In this way the higher temperature steam faces the higher temperature flue gases and provides the best possible steam values. A typical arrangement used to prevent corrosion is to place secondary superheater against the highest temperature flue gas, and the tertiary superheater, which is usually the last one, after the secondary superheater where the flue gases are cooled by the secondary superheater.

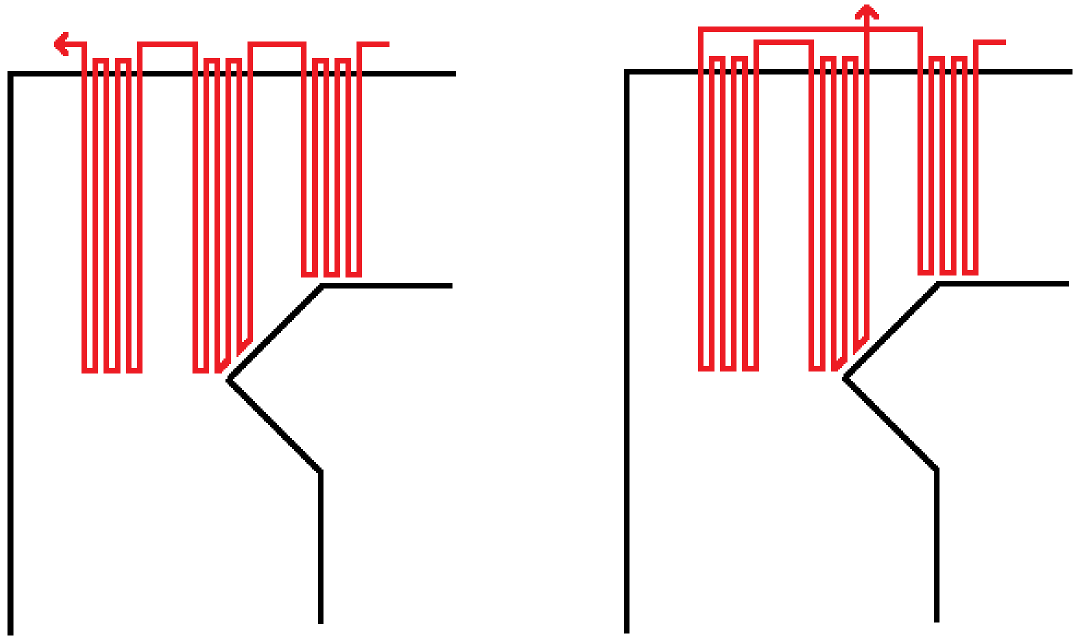

Figure 3.1: Counter-current arrangement and typical corrosion preventing arrangement of three superheaters

Circulated fluidized bed boilers allow superheater to be placed in the loop seal, which is part of the bed material circulation system. Flue gases and flue gas caused corrosion are not present in the loop seal, but the bed material movement and high temperatures can cause problems with this kind of arrangement. Special materials are often needed to prevent these problems.

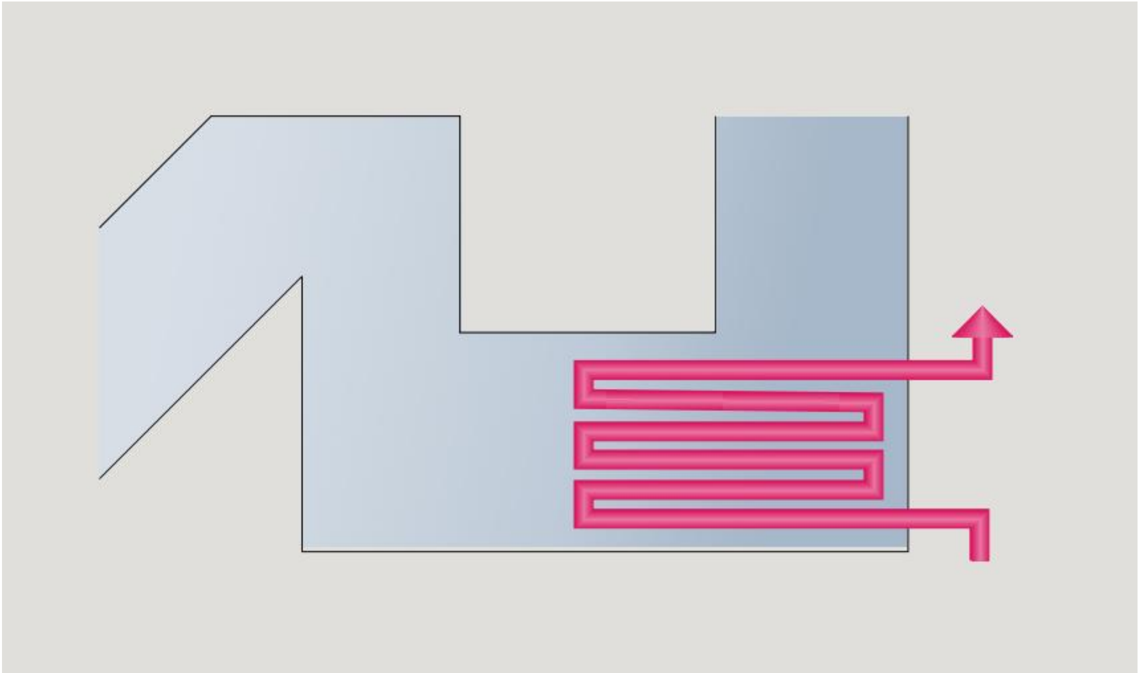

Figure 3.2: Superheater arranged in the loop seal.

Alkali-chlorine-induced corrosion has a threshold material temperature of 450 °C. Below that temperature low alloy steels can be used. In higher temperatures it is preferred to use more expensive high-chromium alloys, such as TP310HCbN to prevent corrosion damage. Lower quality alloy may be for example 10CrMo9-10. (Roppo, Salmenoja 2000)

3.3 Sulfur injection

High temperature corrosion of superheaters may be reduced by changing the flue gas composition. As discussed in chapter two, increase of SO_2 or SO_3 contents in the flue gas reduce chlorine contents in superheater deposits thus reducing corrosion. Sulfur oxides react with alkali chloride with following reaction, where "M" is Na or K:

$$2MCl_{(g,c)} + SO_{2(g)} + \frac{1}{2}O_{2(g)} + H_2O_{(g)} \rightarrow M_2SO_{4(g,c)} + 2HCl_{(g)} \tag{3.1}$$

Sulfation reaction is faster with SO_3 as sulfating chemical. The HCl produced in the reaction escapes the boiler with flue gases, thus preventing the chlorine from accumulating in the ash deposits on superheaters. (Roppo)
The additive feed rate is primarily based on boiler load. This base feed rate is determined based on knowledge of the fuel used and also knowledge based on practical experience in the plant. On top of this base feed rate a correction factor may be applied based on the on-line corrosivity measurements. Metso Corrored analyzer data may for example be used to determine the correction factor. The corrosion risk index that is derived from the analyzer data is used in Metso DNA Corrosion Manager product. The additive feed rate is then determined as the following formula.

$$R_S = k * U * c \tag{3.2}$$

Where
R_S = Sulfur additive feed rate [kgS/h]
k = Base additive feed curve [kgS/MWh]
U = Boiler load [MW]
c = Correction factor

Correction factor is determined using fuzzy optimization logic tools developed for combustion optimizations. Operator displays have functions to determine minimum and maximum additive feed rates as well as minimum and maximum value of the correction factor. The additive feed rate is also adjusted if SO_2 level, SO_3 level or HCl level in the flue gas is close to the limit value set for these emissions. A PID-controller is then added to control the additive flow rate. (Almark et al. 2013)

3.3.1 Metso CorroStop sulfate injection system

Metso have gained good results from CorroStop sulfate injection system implemented in bubbling fluidized bed boiler. CorroStop system operates by injecting ferric or aluminum sulfate to the upper furnace upstream of the superheater region. Sulfates are injected as water solutions by nozzles to the furnace. Sulfates destroy alkali chlorides before they accumulate in deposits on superheaters.

Sulfates are injected with nozzles from one optimal level and from one assisting level. The main injection level is located at the nose height and the assisting level is next to the secondary superheater. Combustion should be completed at the level of injection, but at the same time the injection level should provide enough residence time before the superheaters to allow the chemical reactions to occur. It is important to achieve full coverage of the furnace cross section with the injection. Dosing rate has so far been depending on empirical evaluations of combustion behavior of different fuels. The rate control can be fine-tuned with the SO_2 and HCl from the continuous emission monitoring system (CEMS) after the boiler.

(Roppo, Silvennoinen et al.)

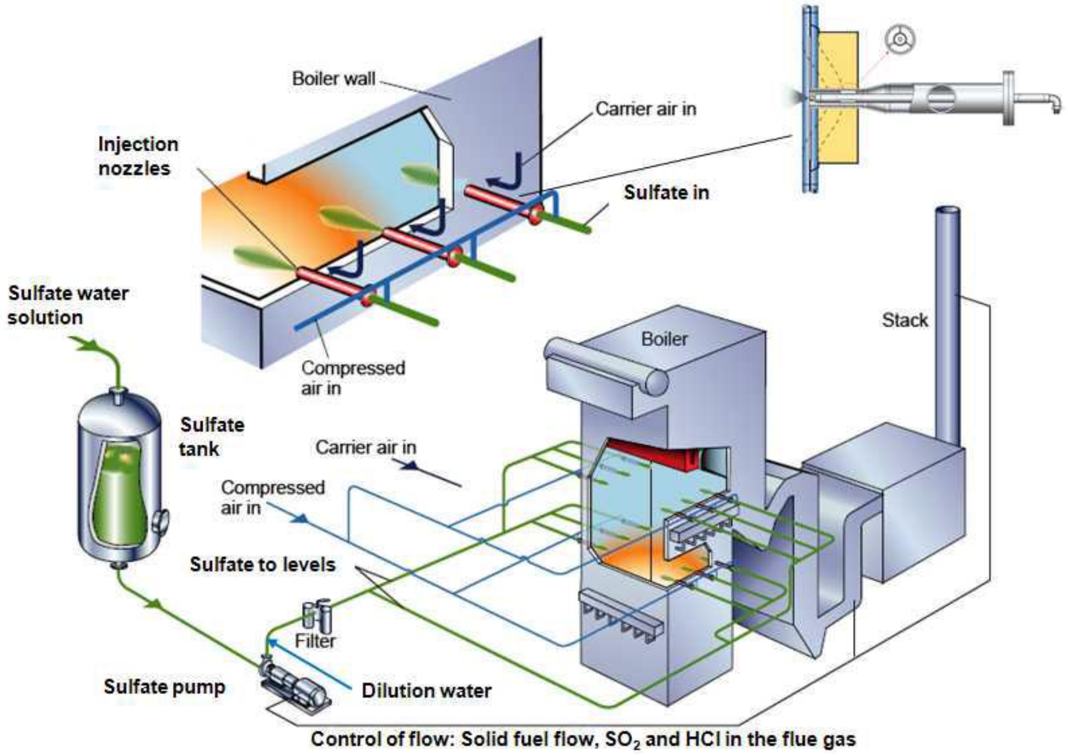

Figure 3.3: Metso Corrostop sulfate injection system (Silvennoinen et al.)

Controlling of the sulfate flow will be done with a pump that controls the l/h solution flow rate. The flow rate may be expressed also as kgS/h if needed. Because sulfate is fed as a water solution, the flow rate can be directly measured. (Almark et al. 2013)

3.3.2 Metso CorroStop+ sulfur injection system

Sulfur addition to furnace atmosphere can also be done with elemental sulfur additive. This technology adds elemental sulfur to fuel before the fuel is fed to the furnace. Elemental sulfur is added as solid sulfur pellets to the fuel flow. Sulfur addition rate is controlled according to the condition of the furnace atmosphere. Controlled value is in kg/h and controlling device is sulfur feed screw where the screw speed is adjusted. Elemental sulfur flow rate cannot be measured directly, and it needs to be calculated. (Almark et al. 2013)

3.4 Fuel diet control

Furnace atmosphere can be controlled also with fuel diet control. The goal of fuel diet control is to optimize the fuel blend of high-chlorine fuels and low-chlorine fuels. Two fuels may also form a couple with high sulfur fuel and low sulfur fuel. This optimization takes into account the corrosivity of the furnace atmosphere and on the other hand the economical and operational restrictions for combustion of low-chlorine or high sulfur fuels. Fuel diet control can be used with Metso Corrostop and Corrostop+ systems as a secondary control mechanism. If additive feed control is not implemented, fuel diet control should be the primary control solution. (Almark et al. 2012, Almark et al. 2013)

Input parameters for fuel diet control include information of fuel prizes, minimum and maximum limits for fuel feeds, manual definition of fuels to use as controlling fuels and target value for SO_2 when one fuel contains significantly high amount of sulfur. These inputs are given by operator from the control display. Fuzzy logics are used in the control solution. The control of SO_2 level often includes limestone feed, which needs to be taken into account in this control application. (Almark et al. 2013)

Fuels are usually mixed far away from the boiler and this causes a significantly long delay in response time in this kind of control. This causes the control to lose its effectiveness. Additional short response fuels may be added to fuel diet control to make it more effective. For example additional coal feed could be added to offer control option if normal fuel diet control offers too long response time. (Almark et al. 2013)

3.5 Control of combustion environment

Final option to control corrosion is to control combustion in the furnace. When corrosion risk rises to high risk level, steam temperature may be temporarily decreased to decrease superheater material temperature. This is done by reducing steam temperature set points at the steam temperature controller. A correction term is calculated and reduced from the set point given by the original steam temperature control. (Almark et al. 2013)

3.6 Environmental restrictions

Corrosion control by additive injection can cause increase in some emissions. Environmental point of view must be taken into account when using additives. Additive injections must not cause emission restrictions to be exceeded. In some cases these environmental restrictions may cause restrictions to corrosion control.

3.6.1 Sulfur emissions

As was discussed earlier, corrosion can be controlled with a sulfur additive. Increase in sulfur content at the furnace causes increase in sulfur oxide content in the flue gas. Sulfur additive should however be used only when sulfur content of fuel is very low. Problems with sulfur oxide emission restrictions are possible, if sulfur additive is used while combusting fuels with high sulfur content. For these reasons the sulfur additive feed rate must be controlled with a control solution that takes into account the real sulfur content in the flue gas and the sulfur emission restriction. When the total sulfur content in the flue gas is close to the emission restrictions the control must not increase the additive feed rate even if corrosion control requires more sulfur. (Discussion, Jaani Silvennoinen)

Sulfur oxides can also easily be removed from the flue gas. This is usually done with wet scrubber reactors using calcium based compounds, such as $CaCO_3$ and $Ca(OH)_2$. These compounds react with sulfur oxides in the flue gas creating $CaSO_3$, which can be removed from the sludge. The $CaSO_3$ may be oxidized further to create calcium sulfate, which can be used for example to make gypsum. Most important reactions in the process are the following, when calcium carbonate is used.

$$SO_{2(g)} + H_2O_{(aq)} \leftrightarrow H_2SO_{3(aq)} \tag{3.2}$$

$$CaCO_{3(s)} + H_2SO_{3(aq)} \leftrightarrow CaSO_{3(s)} + H_2O_{(aq)} + CO_{2(g)} \tag{3.3}$$

$$CaSO_{3(s)} + \frac{1}{2}O_{2(g)} + 2H_2O_{(aq)} \leftrightarrow CaSO_4 \cdot 2H_2O_{(s)} \tag{3.4}$$

These methods can provide as high as 95% removal rate of sulfur dioxides from the flue gas. However the cost of the facilities is high and economical restrictions may prevent the usage of scrubbers in smaller power plants. Less expensive and less effective technologies more suitable for smaller scale exist. These usually contain a spraying system of calcium sludge. (Raiko et al. 2002)

3.6.2 HCl emissions

High HCl emissions are harmful for health, especially for the respiratory system. For this reason HCl emissions are monitored and controlled with high risk fuels. In the year 2000 the European Union directive was put in operation to restrict HCl emissions to

10mg/m^3 in plants combusting recycled fuel. As was discussed earlier, the goal of the sulfur additive systems is to prevent corrosion by forcing chlorine to form compounds with hydrogen instead of alkalis. This way the amount of HCl in the flue gases increases. Also because this kind of corrosion control is used when chlorine content of fuel is high, HCl in flue gas may cause problems with the EU emission restriction.

Calcium compounds are also effective in reducing amount of HCl in the flue gas. Reactions include following.

$$CaO_{(s)} + 2HCl_{(g)} \leftrightarrow CaCl_{2(s,l)} + H_2O_{(g)} \tag{3.5}$$

$$CaCO_{3(s)} + 2HCl_{(g)} \leftrightarrow CaCl_{2(s,l)} + H_2O_{(g)} + CO_{2(g)} \tag{3.6}$$

These reactions take place in a temperature range of 500-600 °C, although with high enough calcium content in the furnace, high enough reaction rates can be achieved in fluidized bed boilers where temperature is around 850 °C. In these conditions it is suggested that the reactions to reduce HCl occur in flue gas after the furnace in lower temperature with inert calcium. HCl can be effectively removed also in wet scrubbers used in sulfur oxide removal process. (Raiko et al. 2002)

3.7 Restrictions caused by other issues

Some other issues may cause more restrictions to corrosion control. These are often related to production issues of the plant or may be caused by some structural issues in the plant design. The nature of these issues is often unexpected and solutions to overcome these issues are plant specific. Here are only some examples of issues already faced with the design process and in the pilot project.

When controlling the corrosion with fuel diet, the feeding system of fuels may cause significant restrictions. The fuel feed mechanisms may offer only a very narrow operation areas in which they can be controlled. While fuel diet control would need a range of 0-100% controllability in different type of fuel feeds for optimal control, the lower feed rates cannot be usually achieved.

Other issues in the fuel feed system causing some restrictions are the fuel storage issues, which may cause serious delays to the control or may restrict the variety of available fuel qualities. These issues are plant specific and solutions to overcome these issues may be achievable. The amount of different fuels in storage may also cause restrictions to control. Fuel diet control cannot be operational if there is a shortage of some fuel type needed.

Some issues in production may also restrict the corrosion control. For example if power demand is high, features in the corrosion control may need to be bypassed in order to reach to power output demands. Operational issues include also the possible high cost of some control fuel that may cause the control to be restricted.

4 METSO DNA CORROSION MANAGER SOLUTION

Metso Fuel Diet product provides customer with new possibility to monitor the boiler condition and to control corrosion in the area of superheaters. The information and control application in this product is named Metso DNA Corrosion Manager. With this product customer can foresee corrosion problems in a new way and may avoid unplanned and unnecessary shutdowns. New opportunities to plan service periods and maintenance actions are made available. Customer is also able to optimize fuel consumption in fuel cost basis in a more effective manner. Fuel costs may be compared to approximations of the maintenance costs caused by superheater corrosion. (Almark et al. 2012)

4.1 Requirements

This part describes the requirements specified for the Metso DNA Corrosion Manager solution. Details of the technical solutions and technical specifications are described later in this document.

4.1.1 On-line measurement measuring the corrosivity of the furnace atmosphere

The measurements to make the corrosion control possible should work on-line. These measurements should measure the corrosivity of the superheater environment of the furnace. This means for example the measurement of the S/Cl ratio of the flue gas in superheater region of the furnace. The measurement should provide information of total chlorine and sulfur or alkali chlorides and SO_2, depending on measurement technique. Other values needed are information about fuel blend Cl content. This may be approximated from flue gas chlorine measurement in the chimney. The measurements should be quick and reliable enough to make control actions for additive injection possible.

Other process measurements needed include temperature measurements of steam and flue gas in superheater region. Also superheater material temperature is needed, but it is usually approximated with steam temperature measurements and technical know-how. Also information of boiler load is needed. Other needed process measurements are the measurements of the additive feed system, if additive feed is present. (Almark et al. 2012)

4.1.2 Data collection

All measurement values must be collected and saved in a database. Also calculation parameters are saved in a way that Metso boiler specialists have access to them and may change them. Metso's specialists should be able to chance the parameters remotely, and should also be able to access corrosion data remotely. In order to retroactively update the calculation formulas and methods, all data should be saved from the first possible moment. (Almark et al. 2012)

4.1.3 Calculation of key corrosivity figures

Corrosivity index and corrosion rate are calculated from the measured values in calculation application. Also cumulative corrosion and fuel chlorine content should be calculated. Approximation of remaining superheater material lifetime can be made with these calculation results. Calculation results are saved in a database. Recalculation of corrosion risk index must be made possible.

Calculation formula is to be encrypted and saved in a database. Calculation formulas are based on Metso boiler know-how and Metso's boiler specialists must have access to make changes to these formulas. The change history of calculation formulas and calculation parameters must be saved. The updates in to the calculation formula must be made able to do remotely. (Almark et al. 2012)

4.1.4 Informative and user frendly user interface

Superheater environment corrosivity is followed by operator with a user interface. The user interface is required to be informative and user friendly, and these subjects are considered to be of great importance in the design process of this application. From the user interface the operator should be able to follow the values based on this new way to measure corrosivity instead of other older measurements indicating the corrosivity of the furnace atmosphere. The operator should also be able to use the new control functions installed to control the corrosivity with this user interface.

At least the quantified corrosion risk index, corrosion rate and the remaining material thickness of the superheater tubing should be always visible to the operator. All relevant process values affecting corrosion should be visible in the user interface. These include at least boiler load, flue gas temperatures, superheater material temperatures, steam temperatures, SO_2 level and additive feed rate. Also the information from the Corrored analyzer should be visible for the operator.

A significant amount of attention should be given on the design process of the user interface to make it clear, detailed and understandable enough to be used daily. The interface should be attractive enough to make the operator choose to use it regularly and keep it visible at all times. (Almark et al. 2012)

4.1.5 Reporting

Along with the user interface a report is needed to give information about corrosion. This report serves mainly the needs of the plant management in planning plant production optimization. Power plant fuel diet cost is optimized against the costs of corrosion risk and maintenance. The report also provides a tool to plan maintenance shutdowns of the plant. The report gives also information about fuel blend chlorine content, which is needed in fuel supply agreement negotiations. (Almark et al. 2012)

4.1.6 Controls

More benefits from the application may be achieved with including controls in the scope of the application. To have a reliable control a reliable measurements and calculations are also needed. A control application tries to optimize the furnace atmosphere according to these measurements and calculations. The atmosphere of the furnace is controlled by adding sulfur to the combustion process. This can be done with additive feed or by fuel diet control, where fuel with higher sulfur content is added to furnace. Also steam temperature may be controlled. Advanced controls are built on Metso DNA control system and they are done using fuzzy logic control. (Almark et al. 2012)

4.2 Metso DNA platform

Metso DNA is a Metso Automation distributed control system (DCS) product. It is an automation and information platform for process control (Figure 4.1). It is designed to cover all needed control and process information functions in a single platform. It also covers all safety instrumented systems and batch solutions. The size-range of systems that can be covered with Metso DNA platform may vary greatly.

First of the three activities the Metso DNA platform consists is the user interaction. The base of user interaction design is to offer access to same information for everyone from control room to plant management level. Intuitive tools for users and communities are used to offer realistic view of the process and to interact with it.

Secondly automated process activity covers all automatically working functions. It includes controls and optimizations as well as field interfaces and buses. Distributed and centralized solutions are supported. Also connections to third party systems are supported. Information collection provides history data to be achievable. High standard of safety level is achieved with safety instrumented systems integration.

Third part is the secured lifetime activity. It contains engineering tools to maintain the platform performance. It provides safety for the automation investment also in the future. (Metso DNA technical overview)

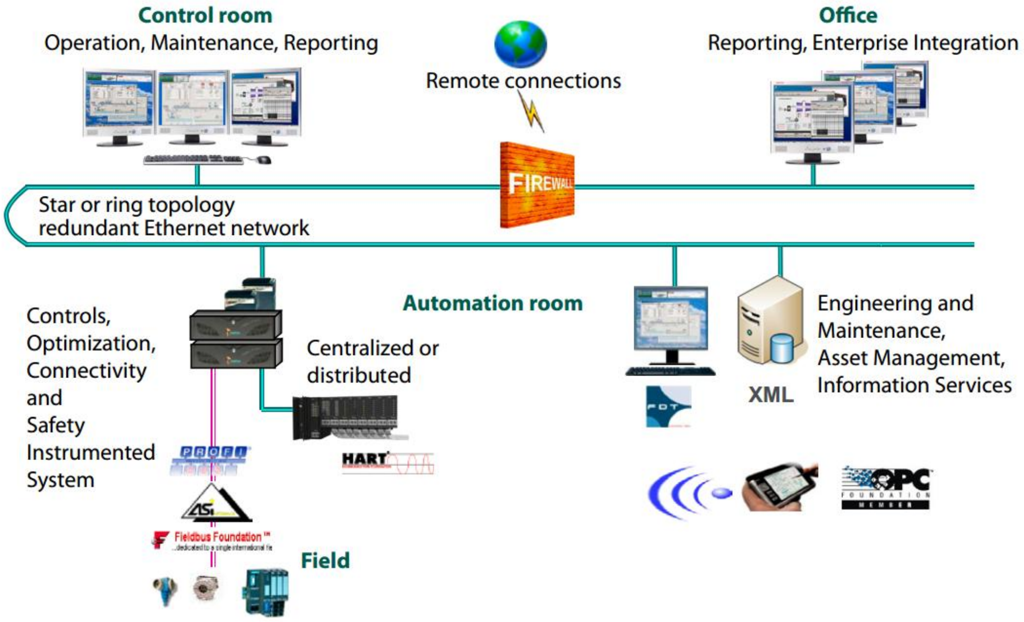

Figure 4.1: Metso DNA platform

Metso DNA Information solution provides customer with the history data of the customer's process and tools to analyze this data. History data of the process is saved in the DNA Historian database where the data is kept for a long period of time and where it is also available for analysis. DNA Historian provides also a calculation environment for further data analysis. Metso DNA Report offers the customer tools to view the data with more informative views, like trends and reports. (Metso Automation)

4.3 Corrored Analyzer

On-line measurement of the furnace atmosphere corrosivity is handled with Metso Corrored analyzer. The analyzer consists of two units. First unit is the sampler unit SDG-100. It is located in the superheater area of the furnace, where temperature may rise as high as 950 °C. The sampler collects samples of the flue gas. Because corrosive chlorine and sulfur are known to be in either gas phase or condensed to very small particles smaller than 0.5 µm in diameter, a cyclone is included in the sampler to blow bigger particles than 10 µm in diameter back to boiler. After this the sample is dissolved in to de-ionized water. A vacuum pump then sucks the solution to the analyzer unit.

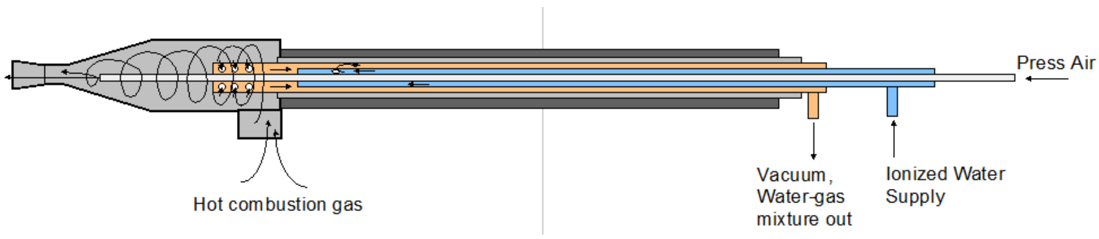

Figure 4.2: Corrored sampler unit

The second unit is the analyzer unit. Chlorine and effective sulfur content is measured using titration technique, where sulfur is titrated as SO_4. A calculation is then executed to transform titration result from mg/l to mg/m^3 in the flue gas. These results are then used to calculate flue gas S/Cl molar ratio, which is later used in the corrosion risk calculation. For the calculation of fuel chlorine content the flue gas chlorine content is also determined. The titration of the sample takes 10-15 minutes, for which reason the analyzer provides new measurement values with this interval. (Silvennoinen et. al. 2013)

Figure 4.3: Corrored analyzer unit

4.4 Metso DNA Corrosion Manager functionality

This part of this thesis work describes the functionality of Metso DNA Corrosion Manager application. Development of the application was done in a project team, and the solutions described in this thesis are results of the work by this whole project team. Simultaneously with the development project was executed the pilot project to Kuopion Energia Haapaniemi 3 plant. This pilot project supported greatly the development project. The pilot project is described later in the chapter 6. Also the development of the user interface is derived as an own chapter.

4.4.1 Requirements of different user groups

There are several different user groups with different needs that will be using this application. Needs of every group should be fulfilled with the design of this application. At the customer there are two groups: Operators and plant management. At the Metso side there are three groups recognized with different needs: Corrored analyzer service engineer, service specialist from Metso Power and service specialist from Metso Automation.

Needs of the operators are at the on-line monitoring and control application. Operator need reliable measurements and informative user interface to read them from. This application offers operators a way to follow corrosion measurements from Corrored analyzer. Operators are also responsible for the usage of the control application. With this application a user friendly user interface is included to offer operators best possible way to use the control application.

Plant management sector needs more long term information for production management optimization. This application provides a way for plant management to optimize power plant fuel diet against costs and risks of corrosion. A way to plan maintenance shutdowns due to corrosion is also provided to optimize the lifetime of surperheaters. Management is provided also with information about the fuel blend Cl content to utilize in fuel supply agreement negotiations.

From the Metso side the analyzer service engineer requires information about the analyzer condition remotely. Also Metso Power and Metso Automation service specialists need a remote connection to this application. Power service specialist requires also additional information about the analyzer results and the surrounding process for customer service purposes as well as for product development. Automation and Power service specialists require also remote access to make certain changes to the functions of the application. (Almark et al. 2012) (Almark et al. 2013)

4.4.2 Data collection

All measurement data is collected to Metso DNA Historian database, where it is available for reporting and corrosivity calculation. Configuration of data collection is done using Metso DNA Engineering tools. Metso DNA Historian Process Controller Interface is used to collect data from Metso DNA Process Controller.

Data collection is configured for the new measurements received from the Corrored analyzer. Other data that must be added to Metso DNA Historian collection are all output values from the calculation and control applications. Control application need also the manual control values to be collected. These are the values that the user changes when operating the control application from the control display. (Almark et al. 2013)

4.4.3 Configuration of calculation application

Calculations in this application are based on calculation formulas that are encrypted and saved in SQL database. For this reason a tool was developed to encrypt and save formulas to the database. The tool is implemented using Metso DNA Historian Web Service Interface. The tool is operated from a web page, (Figure 4.4) where calculation formulas are inputted in text fields. Encrypter is then executed and encrypted formulas are saved in the SQL database. If an empty field for some formula is given, the tool will decrypt the previous formula and then encrypt it again and save it to the database. The encryption is done by using both asymmetric and symmetric cryptography.

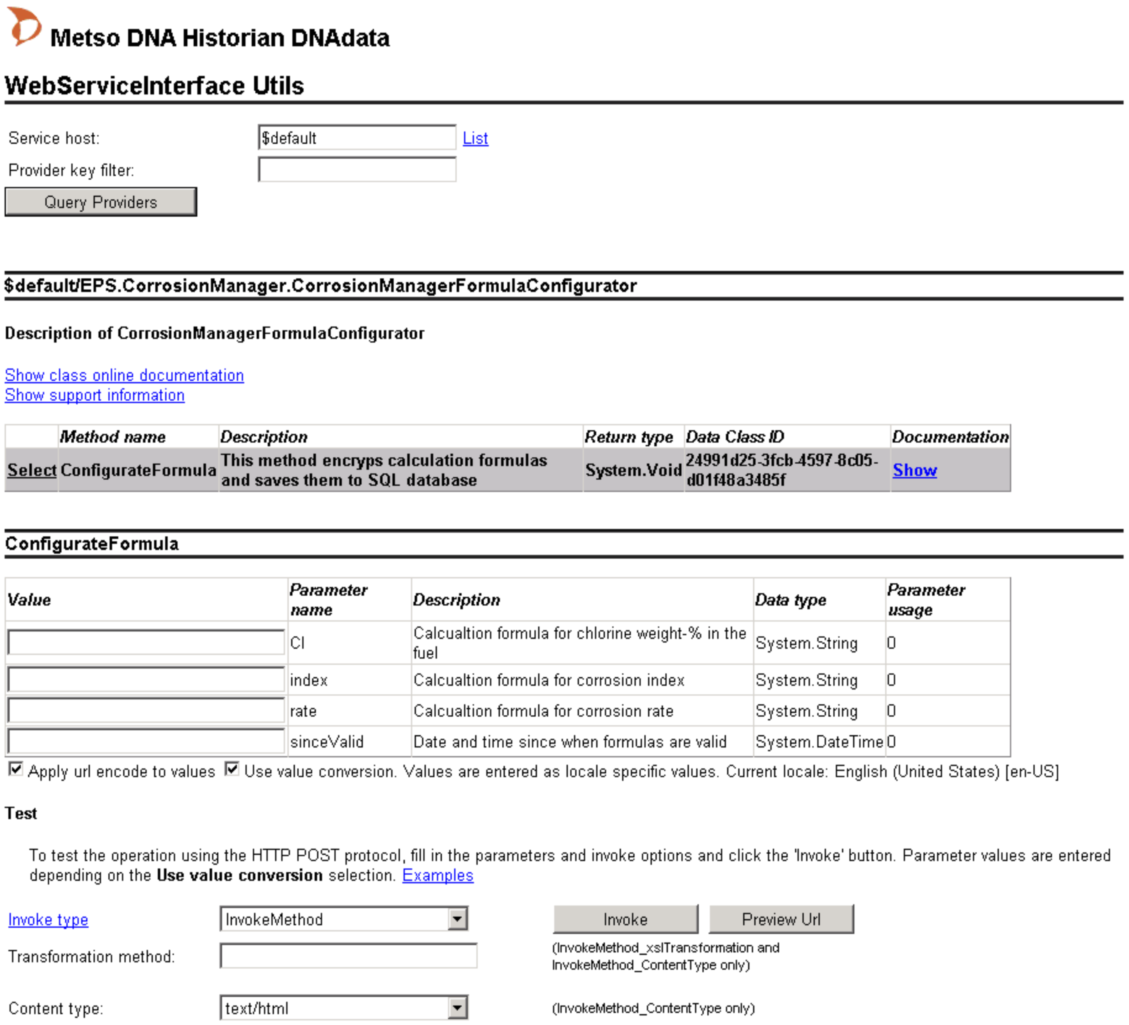

Figure 4.4: Calculation formula configuration tool

Entered formulas must follow a specific syntax. This syntax specifies the use of mathematical expressions and use of variables and parameters. If the syntax is not followed, calculation outputs will not have real values and output status will be “bad”. The configuration tool does not give any warning if syntax is not followed and saves the faulty formula to the database. A feature that checks the syntax of input formula is considered as a future development area.

Parameters used in the calculation formulas are saved in Metso DNA Historian database. For the parameter entry and maintenance a DNA Report Manual Data Entry –tool is created. (Figure 4.5) In the tool there is an input field for all parameters. If the input field is left empty, the parameter is not updated. (Almark et al. 2013)

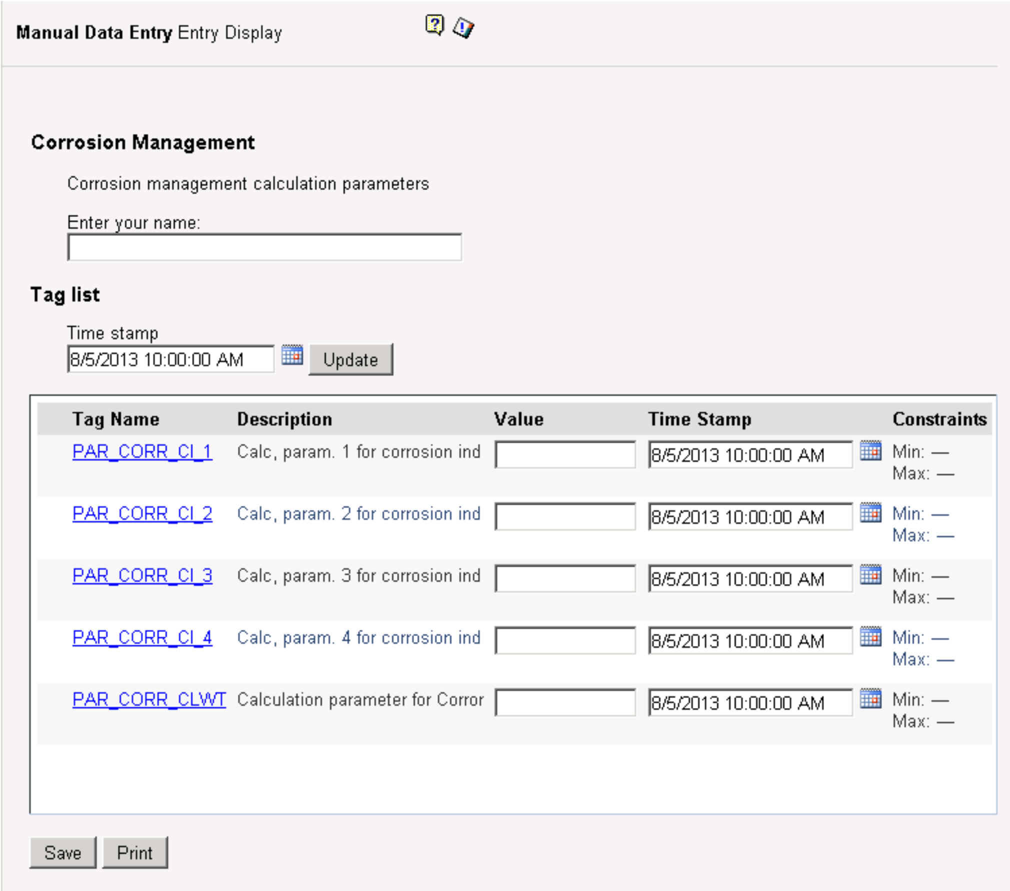

Figure 4.5: Calculation parameter configuration tool

4.4.4 Calculation of key figures

The calculations for DNA Corrosion Manager are implemented using Metso DNA Historian Calculation environment, which is a collection of tools for process history based calculations. Calculations in this environment can be either dynamic or compiled. In this case a compiled calculation package is created. MS Visual Studio C# programming environment together with DNA Historian tools and calculation libraries are used to develop compiled calculation packages. Calculation packages are then implemented to a scheduler application that executes the calculations at given interval.

The corrosion risk, corrosion rate, cumulative corrosion and fuel total chlorine weight-% are calculated as a function of certain measurements. The average values of the measurements for the calculation cycle are used in the calculation. The measurements and parameters for the calculation are read from the Metso DNA Historian database, so each input must be referred with individual tag name. The output values are also saved in Historian database and a specific tag name is required. Tag names may be given defined in to the calculation package or they may be defined with DNA Historian Calculation Designer, which is a web tool that is also responsible for configuration of the calculation scheduler settings. (Figure 4.6)The start time of the calculation cycle is set as the timestamp of the calculation result.

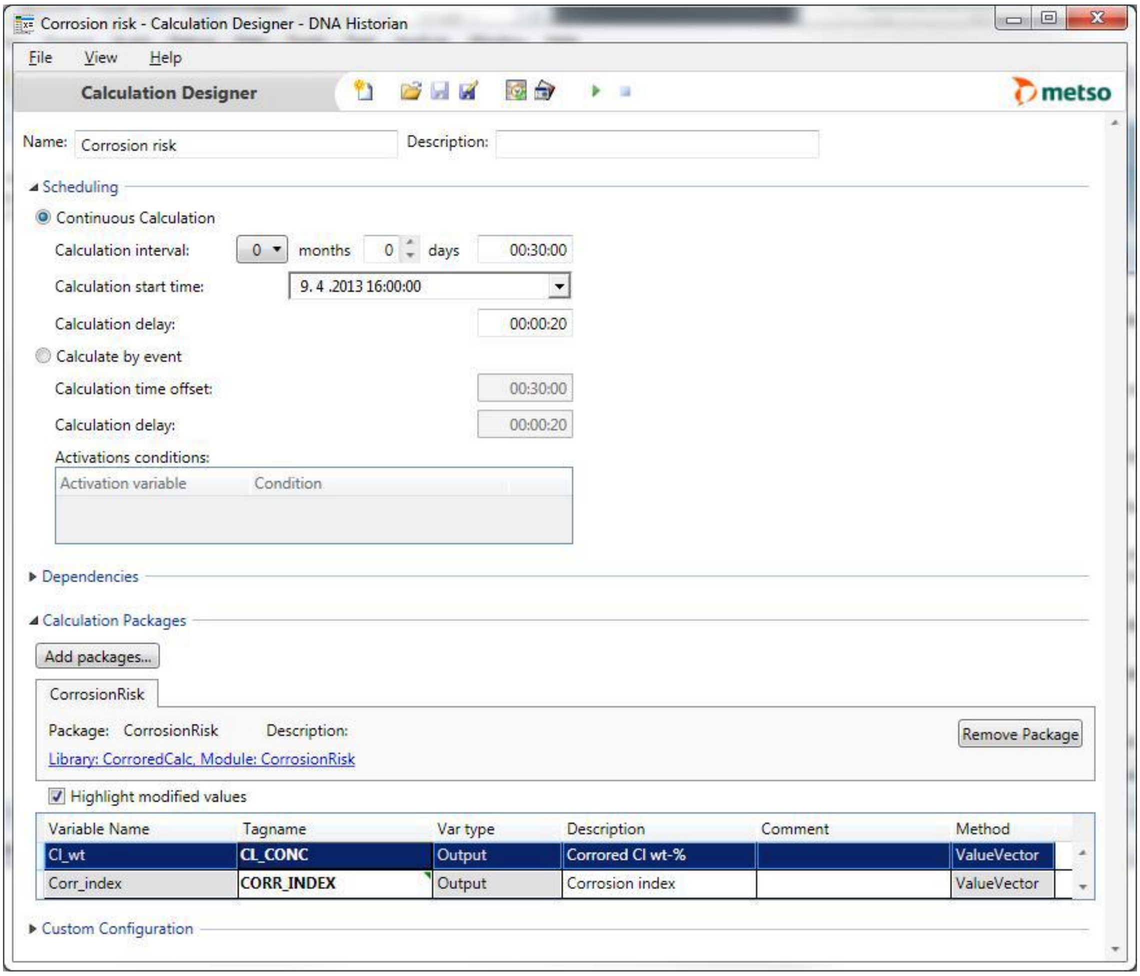

Figure 4.6: Metso DNA Historian Calculation Designer

The total fuel chorine weight-% is calculated with titrated Cl concentration in the flue gas. The titrated concentration measurement is provided by the Corrored analyzer. The Cl concentration is corrected with measured oxygen percentage in the flue gas before calculation.

For the corrosion index calculation are needed S/Cl ration measured by the Corrored analyzer, oxygen corrected chlorine concentration in the flue gas, material temperature of the superheater and the flue gas temperature at the superheater region. The S/Cl ratio is corrected with coal share if coal is used as a fuel. In addition to the measurements used with corrosion index calculation, the corrosion rate calculation needs also oxygen corrected SO_4 concentration in the flue gas.

The cumulative corrosion is calculated with the corrosion rate calculation result. It provides a rough estimate of the total corrosion of the material. Each time the material thickness is actually measured, the cumulative corrosion is corrected to the measured value. The worst case principle is used to choose the measurement value where corrosion has been the fastest. The cumulative corrosion sum is then recalculated from the timestamps of the measurement time to the present moment. The cumulative corrosion result and corrosion rate result can be used further to calculate approximation of remaining superheater material lifetime.

Status of the calculation is followed by a watchdog signal. There is also validity limits set for calculation results. If results exceed these limits an alarm of abnormal operational environment is generated and control application outputs are set into fail safe state. (Almark et al. 2013)

4.4.5 Reporting

Metso DNA Report environment is used to design needed reports for this application. One report is designed to fulfill the needs of plant management. (Figure 4.7) The report is designed to give sufficient information for the plant management to be able to optimize power plant fuel diet against costs and risks of corrosion. The report provides also sufficient information for the plant management to be able to plan maintenance shutdowns due to corrosion and to maximize superheater lifetime. The report provides also information about the fuel blend chlorine content that can be used in fuel supply agreement negotiations.

SUPERHEATER CORROSION metso

06-2013 Print time: 31.7.2013 13:14

Primary superheater

Date	Risk index %	Corrosion rate mm/a	Cumulative corrosion mm	Corrosion margin mm	Material °C	Flue gas before °C	Steam after °C
01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
03	0,00	0,00	0,00	0,00	0,00	0,00	0,00
04	0,00	0,00	0,00	0,00	0,00	0,00	0,00
05	0,00	0,00	0,00	0,00	0,00	0,00	0,00
06	0,00	0,00	0,00	0,00	0,00	0,00	0,00
07	0,00	0,00	0,00	0,00	0,00	0,00	0,00
08	0,00	0,00	0,00	0,00	0,00	0,00	0,00
09	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	0,00
19	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25	0,00	0,00	0,00	0,00	0,00	0,00	0,00
26	0,00	0,00	0,00	0,00	0,00	0,00	0,00
27	0,00	0,00	0,00	0,00	0,00	0,00	0,00
28	0,00	0,00	0,00	0,00	0,00	0,00	0,00
29	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Average	0,00	0,00			0,00	0,00	0,00
Minimum	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Maximum	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Monthly total corrosion	0,00
Minimum allowed material thickness	0,00

Figure 4.7: Layout example of corrosion report for plant management, page 1

SUPERHEATER CORROSION

metso

06-2013 Print time: 31.7.2013 13:14

Secondary superheater

Date	Risk index %	Corrosion rate mm/a	Cumulative corrosion mm	Corrosion margin mm	Material °C	Flue gas before °C	Steam after °C
01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
03	0,00	0,00	0,00	0,00	0,00	0,00	0,00
04	0,00	0,00	0,00	0,00	0,00	0,00	0,00
05	0,00	0,00	0,00	0,00	0,00	0,00	0,00
06	0,00	0,00	0,00	0,00	0,00	0,00	0,00
07	0,00	0,00	0,00	0,00	0,00	0,00	0,00
08	0,00	0,00	0,00	0,00	0,00	0,00	0,00
09	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	0,00
19	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25	0,00	0,00	0,00	0,00	0,00	0,00	0,00
26	0,00	0,00	0,00	0,00	0,00	0,00	0,00
27	0,00	0,00	0,00	0,00	0,00	0,00	0,00
28	0,00	0,00	0,00	0,00	0,00	0,00	0,00
29	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Average	0,00	0,00			0,00	0,00	0,00
Minimum	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Maximum	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Total monthly corrosion	0,00
Minimum allowed material thickness	0,00

Figure 4.8: Layout example of corrosion report for plant management, page 2

SUPERHEATER CORROSION metso

06-2013 Print time: 31.7.2013 13:17

	Process									
Date	Fuel power MW	SO2 in chimney mg/Nm3	HCl in chimney mg/Nm3	Corrored S/Cl	Corrored Cl mg/Nm3	Fuel Cl %	Fuel S/Cl	Fossil/ Renewable	Coal MW	Lime kg/s
01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
28	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Average	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Minimum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Maximum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure 4.9: Layout example of corrosion report for plant management, page 3

SUPERHEATER CORROSION

metso

07-2013 Print time: 1.8.2013 9:50

Daily report

Time	Fuel power MW	SO2 in chimney mg/Nm3	HCl in chimney mg/Nm3	Corrored S/Cl	Corrored Cl mg/Nm3	Fuel Cl %	Fuel S/Cl	Fossil/ Renewable	Coal MW	Lime kg/s	Risk Prim %	Risk Sek %
01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
28	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Average	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Minimum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Maximum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sum	0,00								0,00	0,00		

Figure 4.10: Layout example of corrosion report for plant management, page 4

Another report is designed to provide information for Metso power service specialist. This report contains information about the main functions of the Corrored analyzer and the DNA Corrosion Manager application. It also contains information about the condition, possible faults and maintenance needs in the analyzer.

4.4.6 Integration with Corrored analyzer

Corrored analyzer measurement data is used to determine the corrosiveness of superheaters. The measurement data transfer interface to Metso DNA environment is done with Ethernet MODBUS protocol, which is supported by the analyzer unit. This proto-

col transfers the measurement data from the analyzer to DNA environment. Metso DNA has a service named Extension Gate that is responsible for receiving the data.
(Almark et al. 2013)

4.5 Future development

The control solutions including the additive feed have a very good potential to control corrosion with short response times and in this way achieve very effective control. This type of control mechanism has not been available earlier. The best way to improve this control is to improve the measurement technique to operate faster. This way the control would be able to make faster responses to changes in the corrosion risk. For this reason the measurement technique should be the main focus of development in the future.

The application is designed to include also the corrosion monitoring of the superheater in the loop seal. There is however yet no measurement devise able to measure the corrosiveness of the loop seal environment. Developing of this kind of measurement technology should be done in the future.

The DNA Corrosion Manager application provides new information about the composition of the fuel that is combusted in the plant. New information is provided of the chlorine content of the fuel. This data could be valuable in the analysis of different fuel suppliers of the plant. For this reason the DNA Corrosion Manager application would be beneficial to integrate with Metso DNA Fuel Data Manager application, that is designed to control all data about the fuels used in the boiler plant. Other information from the fuel data manager might be valuable also for the DNA Corrosion Manager application, so for this reason also some sort of integration between these two applications should be considered.

Pilot projects are still needed to test the application with different conditions. The application with additive feed control implemented must still be tested. The application should also be tested in a plant combusting recycled fuel.

5 DEVELOPMENT OF USER INTERFACE

One goal of this thesis work is to develop a user friendly and informative user interface for the Metso DNA Corrosion Manager application. User interface creation tool with Metso DNA system is the Metso DNA Operate Picture Designer and the user interface is implemented as Metso DNA Operate displays. The development of user friendly and informative user interface is seen as a high importance aspect in the Metso DNA Corrosion Manager development project.

5.1 About usability

Usefulness of an application consists of utility and usability. When utility describes in which extent the application performs the functions it is required, usability describes how well the application user can use these functions. Whenever there is an interaction between human user and the application, usability issues apply. Interactions include normal use, installation, maintenance and every other possible interaction type that may occur seldom or often when using the application.
Usability can be divided in five different components. These components existing together in an application create good usability. These five components are:

- Learnability: Describes how easy it is for new user to learn the use of the application to get the task of the user done.
- Efficiency: Describes how productive the user can be with the application after the user has learnt to use the functions in the application.
- Memorability: Describes how well a casual user can memorize the use of the application after not using the application for some period of time.
- Errors: The user of the application should perform as few errors as possible when using the application. The severity of the errors should be minimized and the recovery from the errors should be as easy as possible.
- Satisfaction: User of the application should be subjectively satisfied when using the application. The user must find the application pleasant.

When considering usability with these components the measuring of usability is possible. Usability measurements are usually done with a group of test users using the application. It is important to have a similar sort of users in this test user group as are the users who eventually are the real users of the application. (Nielsen 1993)

5.2 Requirements of user friendly and informative user interface

Some rules may be appointed to the design process of a user interface according to the usability. These rule lists are not to be used as a strict set or rules but as general guidelines and as checklists when designing the user interface.

5.2.1 Design Principles

Things that need to be considered in the design process of user interface can be categorized with four different design principles. These principles are:

- Simplicity
- Clarity
- Consistency
- Pleasant appearance

These principles give a guideline for visual design of user interfaces and may also be used as a checklist when evaluating successfulness of the design.
The visual simplicity is achieved after removing all visual details that are not necessary for the use and comprehension of the functions in the user interface. The focus of the user can then only be aimed at essential features. The goals that can be achieved with visual simplicity are:

- Approachability: Offers the user enough visual pointers to understand the functions of the user interface with one glance.
- Recognizability: The design gives the user chance to focus on essential functions
- Immediacy: Simplicity causes the usage of the user interface to be quicker.
- Usability

Clarity aims to visually organize the presented information in the user interface. This is done by using Gestalt principles. These principles base on the users vision to sort single visual details to larger sets. When visual details are placed according to these principles connections between details can be created. These principles are:

- Proximity: Details are positioned close to each other.
- Similarity: Details share some visual ability.
- Closure: Area is closed by some visualization.
- Continuity: Lines that intersect with each other are considered to have a connection.
- Familiarity: When details form some familiar shape they are considered to have a connection.
- Good shape: The user tries to complete incomplete shapes.
- Common fate: When two details move to same direction with same velocity they are considered to have a connection.

- Connectness: Details that are visually connected are considered to have a connection.

Consistency with existing user interfaces either in certain product or product family should be taken into account in the design process. Consistent design features teaches users to use your user interfaces and adapting to new but consistent interface is easier. This kind of inner consistency can be created with details like component placement and usage, color usage, font usage, terminology, similar functionality and similar commands. External consistency with other software, other manufacturers and outside world should also be taken into account.
Pleasant appearance is usually more subjective and depends on users and culture. Few guidelines for pleasant looks include:

- Do not fill the window too tightly with details
- Beware of frames inside frames
- Use Empty space as a separator
- Pleasant size-ratios are more important than minimizing the sizes
- Try to create consistent look in all windows
- Beware of disruptive background

(Haustola)

5.2.2 Composition

Screen balance is affected by the display ratio. Most common ratios today are 4:3, 16:10 and the widescreen ratio 16:9. Unlike printed publications, display layout is institutionally horizontal. Balance inside the display is created by contrast and symbols. Having large dark areas on the other side of the screen when other side is calm and white creates imbalance. Imbalance makes it difficult to read the display with visual tension. Thus it is advisable to avoid it and make displays as balanced as possible. Although too balanced views may bore the user, it creates comfort and confidence.
Golden ratio and golden mean can be used as a guideline for balanced graphical emphasis. Golden mean is the crossing point of diagonal and a line perpendicular against the diagonal drawn through the adjacent corner (Figure 5.1). This is also approximately the point where the Fibonacci spiral ends in displays with 16:10 ratio, which is designed to be close to the golden ratio of 1,618. Objects that are wanted to be emphasized can be placed approximately at these locations. Central position is also a natural focal point. User’s cultural reading direction should be considered as well. The objects that the user should take into account first should be placed in the position of the natural starting place of reading depending on cultural background. In western cultures the reading starts at the upper left corner of the display.

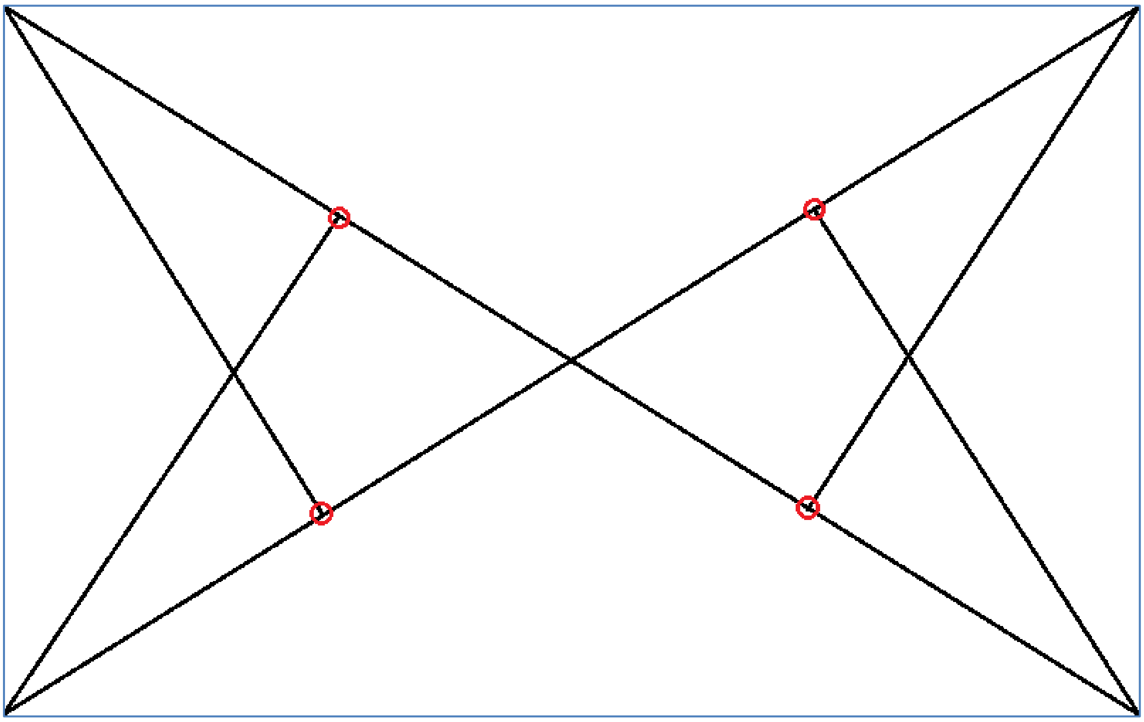

Figure 5.1: Golden mean focus points displayed with red circles

Canonical grid is a useful tool for composing display. It creates empty spaces between objects and makes it easier to create a balanced display. With canonical grid many different sized elements can be placed in the display clearly and symmetrically. The grid shows the locations of columns for different kind of spacing principles. The display may be divided between 2, 3, 4, or 6 columns depending on the current need. Multiple column structures may even be used in different rows, though too many changes in the structure will cause the clarity to vanish. (Haustola)

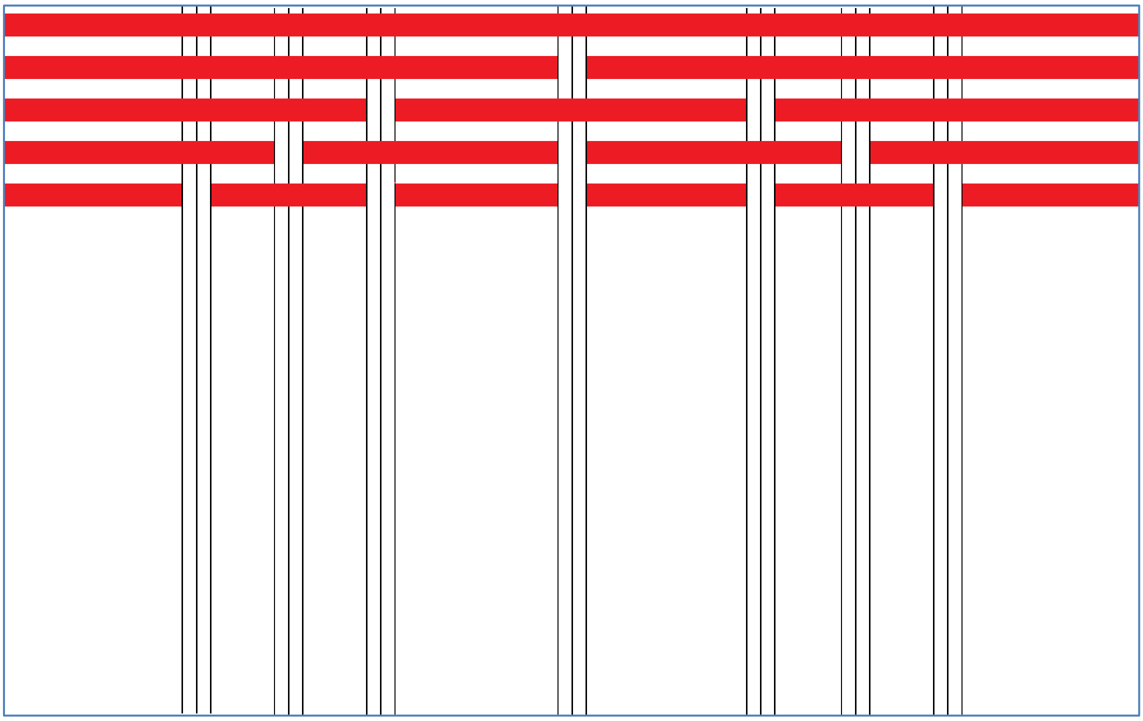

Figure 5.2: Canonical grid

5.2.3 Use of colours

Colors can be used in the user interface for many purposes, that include following:

- Attracting attention
- Clarifying of structures and processes
- Realistic visualization of objects
- To visualize the logical structure of ideas and processes
- Visualization of time
- To add impressiveness and comprehensiveness
- To reduce mistakes in interpretation
- To add redundant visualization of a structure
- To visualize quantity and quality

Use of colors can on the other hand be troublesome in following ways:

- Not good for color blind user
- The eye gets tired when seeing colors, especially when bright colors are used
- Complex use of colors may cause confusion
- Different cultural backgrounds may cause different interpretation.

Colors have different meanings in different cultures. Different cultures include also differences in different fields of industry. Some examples of meanings of some colors.

- Red: danger, hot, fire, stop, anger
- Yellow: attention, warning, heat, activity, sun, new
- Green: you may proceed, safety, nature, peace, freshness, hope, poison

- Blue: coldness, water, sky, ice, cool, true
- White: innocence, honesty, coldness, truth
- Black: darkness, night, death, wisdom, power, sadness
- Grey: unity, hopefulness, conservatism

Colors have three attributes that are shade, brightness and contrast. The difference between brightness and contrast is often not clear. Brightness means basically the amount of white and black in the color, when contrast means the pureness of the color.

When designing user interfaces one should always remember that about 8% of male users and 1% of females suffer from some degree of color blindness. The most usual is the red-green blindness. For this reason no feature of the user interface should be made to rely on different colors used. For example red and green buttons should also have a redundant feature to visualize the difference between them. Some guidelines include:

- Do not use side by side red, green, purple, brown and grey
- Do not use color signals where red changes into green or yellow, or green changes into yellow.
- Use red only on dark background
- Test your display without colors visible
- Avoid color pairs, where RGB-values differ only in red.

(Haustola)

5.2.4 Use of fonts

The use of fonts should also be considered carefully. There are basically two types of fonts available, when there are hundreds of independent font sets to choose from. These two types are serifs and sans-serifs. Serifs are the small features at the end of the letter bodies. For example Times New Roman is a serif font, when Calibri is a sans-serif, which means it does not include serifs in the letters. Here is a word “Corrosion” written first in Calibri and later in Times New Roman.

- Corrosion
- Corrosion

More detailed features can be seen in the later text that is written with serifs. A rule for a user interface designer is that a sans-serif font should be used in all display features, when serif font is better whit long texts.

If some sorts of tables are used, a monospaced font like Courier should be considered. In a monospaced font same amount of space is allocated to individual letter, so for example a word image written in Times New Roman first and in Courier later looks like following:

- image
- `image`

Here can be seen that in Times New Roman a different amount of space is allocated to letters “i” and “m” when with Courier the space allocated for these letters is the same.

Another role to consider is to avoid using only capital letters in the user interface. The capitals are slower to read and require more space. The use of capitals may also be interpreted as yelling and aggressive way of communication. (Haustola)

5.3 User interface of Metso DNA Corrosion Manager

The operator uses the Metso DNA Corrosion Manager application via Metso DNA Operate user interface. The user interface is used to monitor superheater corrosion and to monitor and operate the corrosion control functions. Development of this user interface was seen as a very important part of this DNA Corrosion Manager development project and it was also significant part of this thesis work.

The main goal was to make a user interface that was so attractive and user friendly that operators would be keen to implement it to their daily usage routines. Some information about the corrosivity is to be always visible to the operator. The user interface design principles and usability theory was the basic principles in the design process, along with Metso specific design principles and the abilities of Metso DNA Operate design interface.

The user interface consists of three different objects. Two of them are displays and one is an addition module to an existing display. This one module is designed to contain the most important data about corrosivity in a small space and in a very readable form, so that a fast glance at the module tells as much as possible of the corrosivity of the furnace atmosphere. Then the two displays are an information display and control display. Information display shows all relevant process data concerning corrosion and in the control display there is all functions to use the corrosion control.

5.3.1 Main display module

Operators have learned to operate the plant according to certain routines. This is why it is not easy to force operators to change some of the visible displays to DNA Corrosion Manager displays. For this reason a module was designed to be implemented in some of the existing displays always visible to the operator (Figure 5.3). The main idea was to design a module that shows the most important corrosion figures numerically or visually. Information is also easy and quick to read from the module.

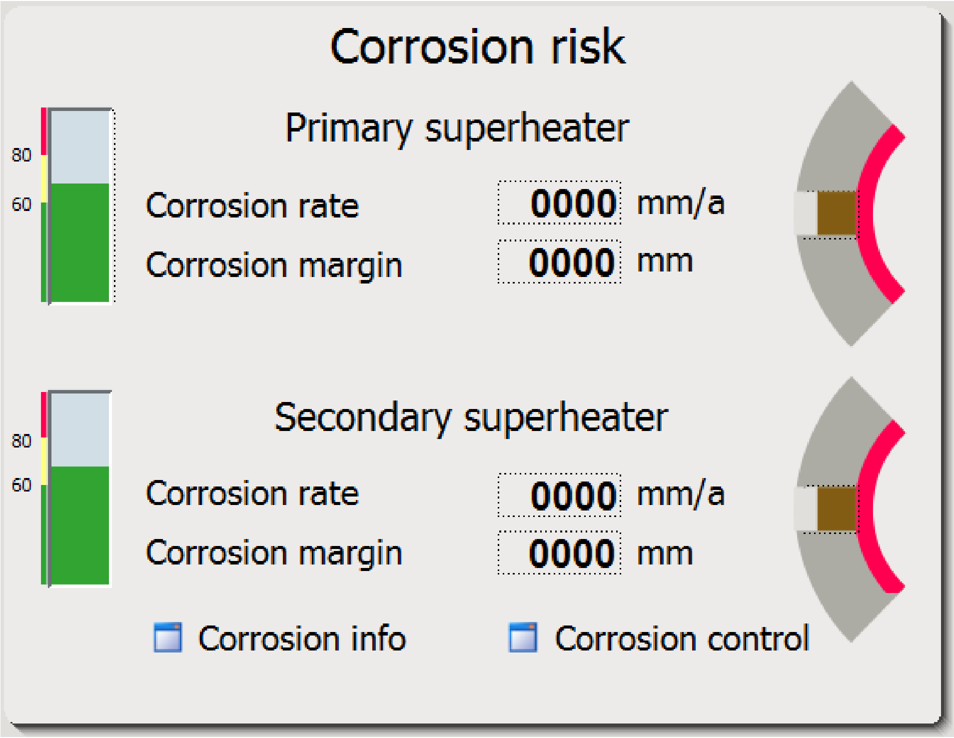

Figure 5.3: Main display module layout

Estimation can be made to figure out if some superheater package faces more severe corrosion risk than others. To get the most important information with a quick glance only the superheater with the biggest estimated risk is shown. In the example picture it is estimated that both primary and secondary superheater may face the most severe risk.
The gauge or gauges in the left side of the module shows the severity of the corrosion risk in a range of 0-100. Threshold values are defined to point slightly severe and severe risk areas. In the picture these values are 80 and 60. The color of the gauge changes according to the severity of the risk between green, yellow and red.
Numerical values of corrosion rate and corrosion margin are shown in the middle of the module. Corrosion rate is shown in millimeters per year [mm/a]. The corrosion margin is a measure derived from the cumulative corrosion figure, and it shows the remaining material thickness to the minimum allowed material thickness in millimeters [mm].
The graphical feature on the right side shows the approximation of the remaining material thickness of the superheater. The approximation is based on measurement and estimate of the cumulative corrosion. The thickness shown is chosen as a worst case measurement. The graphic shows a gauge showing the progress of the corrosion from the full thickness to the minimum allowed value. The red area shows the minimum allowed value of the superheater material thickness, so when the gauge is at zero, the thickness is below the minimum allowed value.
At the bottom of the display there are also two links to the two DNA Corrosion Manager displays. The module is inserted to a relevant main display that operators like to have visible at all times. Plant specific decisions must be made in planning the best display.

Also plant specific decisions are made when choosing the superheaters which data is visible in the display.

5.3.2 Information display

All information about the corrosion of the superheaters is compiled in the information display (Figure 5.4). It is thought that operators may not want to keep this display visible at all times but they may open it when they want to have more information about the corrosiveness and to keep the display visible when high corrosion risk is causing problems. Data shown in the information display include process measurements and calculated values.

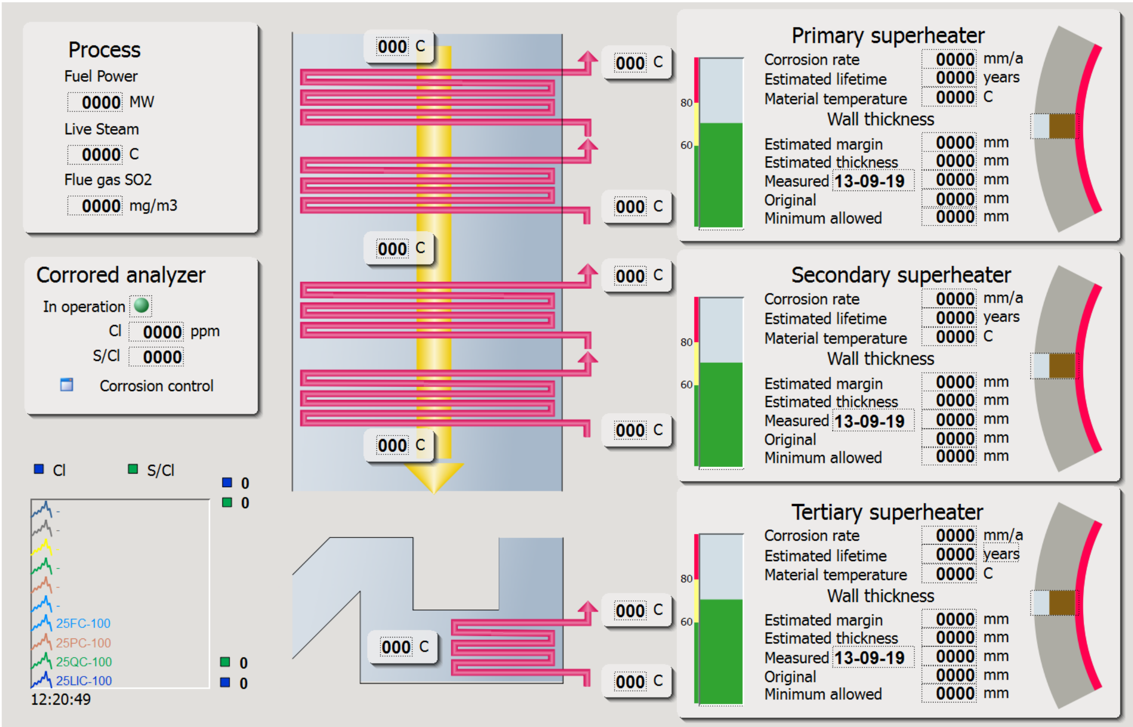

Figure 5.4: Info display layout

All relevant process data that cannot be pointed to specific superheater or to a specific location in the superheater area of the furnace are showed in the left side of the display. In the left, the information from the Corrored analyzer is also shown, along with the status of the analyzer. Analyzer data is also shown in a trend at bottom left. With the analyzer data there is also a link to the corrosion control display.
A graphical model of the superheaters is in the middle of the display. Along with the superheaters in the flue gas area the loop seal superheater may also be displayed, because it is considered as a future development area of the DNA Corrosion Manager application. Temperature data of steam, flue gas and sand in the loop seal are shown in the graphical section of the display. The graphical assembly of the superheaters should be designed specifically for every plant to visualize the actual assembly of the superheaters, which is not similar in every plant.

A set of data boxes including all corrosion related data concerning specific superheater pack, except the temperature data in the graphical section of this display are in the right side of the display. The graphical features of the data box are similar to the graphics in the main display module, but there is more numerical data available. An estimate of the superheater lifetime and an estimate of the superheater material temperature are shown. Wall thickness analysis includes the estimate of the thickness and corrosion margin based on the DNA Corrosion Manager calculation and the measured value of the latest measurement. Also the static original thickness and the minimum allowed thickness are shown.

5.3.3 Control display

Operations of all installed corrosion control functionality from the DNA Corrosion Manager product are visualized in the control display (Figure 5.5). The shape of this display may vary significantly according to the control functionalities installed at specific plants. Also the fuels that are used by the plant affect the details visualized in the display. When there are less control features in the display, information features can be added to fill the empty space.

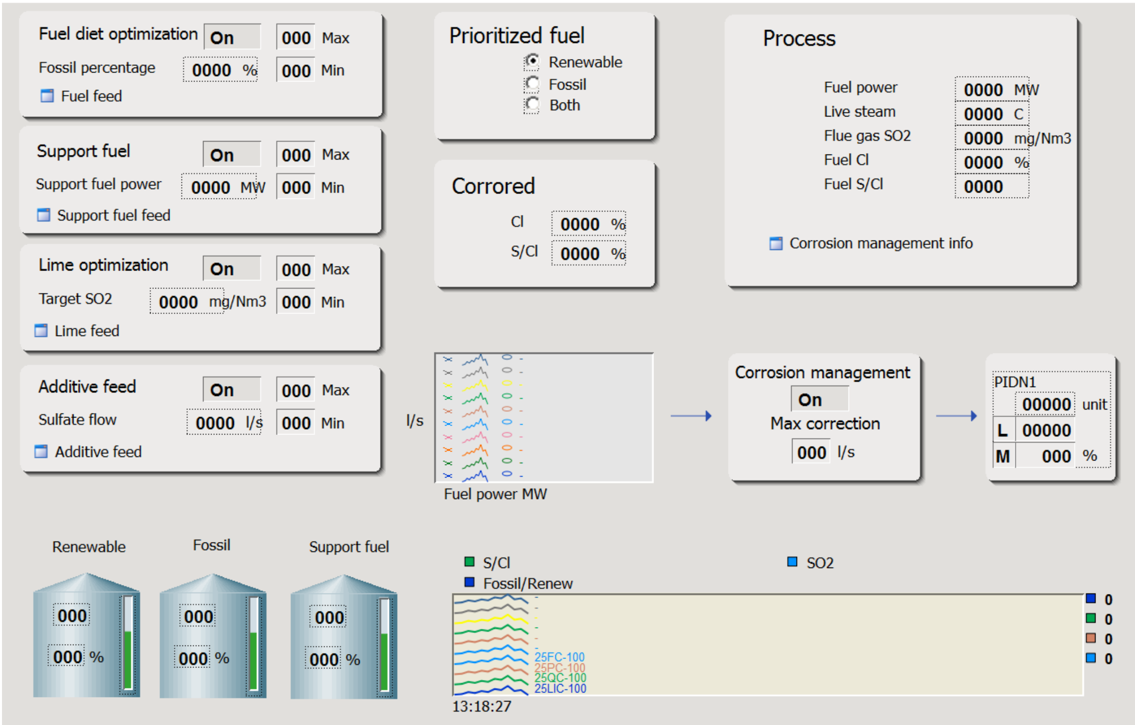

Figure 5.5: Control display layout

In the example picture, the fuel diet control is displayed at the top left of the display. The fuel diet control visualization consists of three similar functionality boxes. One box includes the on/off button for the optimization and inputs for limits for the optimization. Also the control value output of the optimization is shown, but it is not operable. There is also a link to the lower level control display concerning each case of optimization. The three fuel diet controls are the main fuel diet optimization, support fuel optimiza-

tion and lime feed optimization. There is also a prioritized fuel selection box included in fuel diet optimization. This feature is used to choose the primary fuel of use according to the current situation in fuel market prizes or the availability of fuels at the plant.
Additive feed optimization is operated with a similar box as the three boxes in fuel diet control. There is on/off button, feed limit inputs, value of the control output and link to lower degree control. After this there is a visualization of the fuel power/additive feed rate relation. This tells the additive feed rate setpoint without the DNA Corrosion Manager optimization. DNA Corrosion manager optimization creates a correction to this setpoint. This is operated in the next box, where there is an on/off button for the DNA Corrosion Manager optimization and limit value input for the maximum correction. After this there is a visualization of the PID controller of the additive feed.
In the example display there is also information features. Measurements from the Corrored analyzer and other process measurements are shown. Also info of the current availability of different fuels is visualized. A trend or trends may also be added according to plant specific needs.

5.4 Future development

One goal set for the design process of the user interface was to make its use somehow addictive to the user, so that operators using the DNA Corrosion Manager would want to keep using it and to actively pursue better results. Operators should more easily see the positive results of their new kind of actions rather than be satisfied to continue operating the plant as before. Some features should for this reason be added to the user interface or to the application under the user interface to make the operators to want to use the application as effectively as possible. In this thesis work these aspects were given in some focus. But due to limitations in schedule and application environment these aspects are considered to be future development areas. The results of these development aspects are also to cover much wider field in Metso DNA information application product area than just the area of DNA Corrosion Manager -product.

5.4.1 Points of focus

First point of focus is skill improvement. Traditionally operators operate the plant in the comfort zone. This means that they avoid any kind of problematic situations and unnecessary workload. This is of course good goal, but it often leads to drop in the effectiveness of the plant.
With Metso DNA info applications like DNA Corrosion Manager, it is possible to measure the effectiveness of the plant more precisely than before. The next step to consider is to use these plant effectiveness measures to determine the skillfulness of the operator. With this kind of skillfulness measure, the operator can more easily and more willingly make improvements in his work. This may also lead operators to actively pursue the best possible skill index in their work.

Secondly, addition of healthy social competition could be considered. In plants where a small number of operators work with the same part of the process in various shifts, a competition between these skill indexes could be introduced. A competition between different operators could lead to improved willingness to improve the skill indexes.
Effective use of this kind of skillfulness measures need to be made a focal aspect in user interface design. Operator should always understand whether the actions made caused decrease or increase in his skill index, which in the same time means decrease or increase in the plant effectiveness. The skill development feature should be made highly visible and available in the user interface, but it should not disturb the actual operation process of the operator.

5.4.2 Operator skill index visualization

The skillfulness of the operator is difficult to measure with one individual numeric value, because different plant effectiveness indicators cannot be easily combined. Different indicators should also not be hidden under one value. Because of this a way to combine all available plant effectiveness indicators in one unit without hiding individual values is needed.
One way to visualize a varied number of values is a regular polygon scale. The number of vertices in the polygon is chosen according to the number of individual plant effectiveness indicators that are included in the skillfulness measure of the operator. A minimum of three is needed. Now each indicator is represented by one circumradius of the polygon. A scale and the direction of the scale are also chosen. A scale could be for example 0-100 and the direction decides if the value 0 or 100 is in the circumcenter. The scale is visualized also with colors.

Figure 5.6: Pentagon scale as an example of a regular polygon scale

To each circumradius is then created a travelling point indicating the measure of one plant effectiveness measure. These points are connected with a solid line to create o shape shifting polygon. The shape and size of this polygon indicates effectively the skill of the operator. The shape can also be used to indicate the personal operating style of the operator. In the next picture, examples of two different possible shapes with approximately similar sizes are shown.

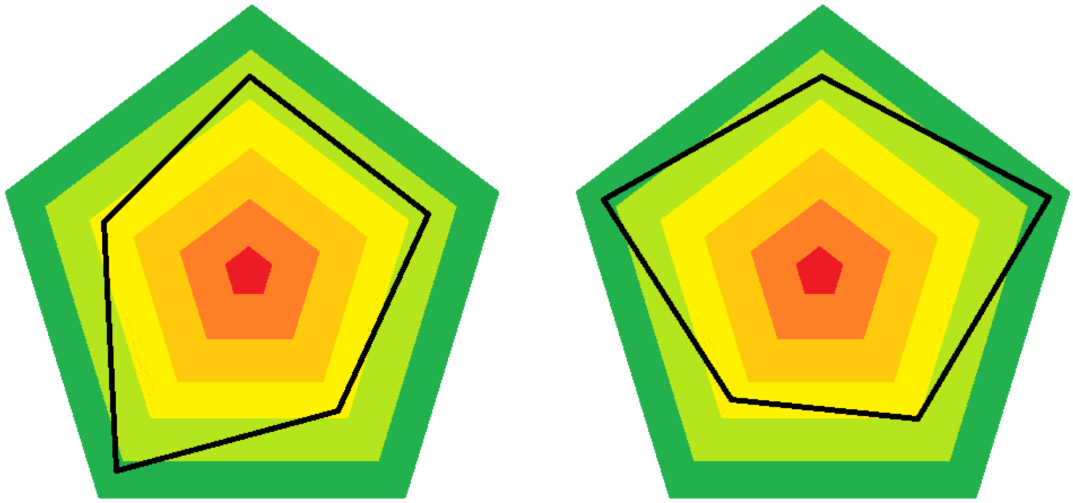

Figure 5.7: Two example polygon profiles in pentagon scale

Each value should be derived individually for each operator or each shift. Values should also be floating averages from a longer period instead of actual current values. This means that these polygon indicators are not to be used in the operating process. Instead they are a way to motivate and develop operators in their work. Because the history data is available for a long period, a visualization of the development process of the operators can also be made.

5.4.3 Action triggered pop-up windows

The design of the main display module was to be informative and at the same time simple and quick to read. This sort of goals could be achieved with information pop-up windows. Triggers for the pop-ups could be for example a cursor movement over some simplified information feature, or some value exceeding a set limit. Inversed actions should also close these pop-up windows. These pop-ups could quickly provide extra information for the operator without a need to change the whole view in the display. Some future development in this area should be considered.

6 PILOT PROJECT AT KUOPION ENERGIA HAAPANIEMI 3

This part of this thesis work describes the pilot project where Metso DNA Corrosion Manager application was installed as part of Metso Fuel Diet^{TM} product. The project was delivered to Kuopion Energia Haapaniemi 3 plant, where it was installed to Metso CYMIC boiler.

6.1 Kuopion Energia Oy

Kuopion Energia Oy is a Finnish energy company owned entirely by city of Kuopio. The company operates in energy and district heat production business. The company was separated from the city organization in 2007, but the history runs back to early 19th century. The company has approximately 100 employees at the moment.

The energy production of Kuopion Energia is focused on Haapaniemi plant area, where there are two boiler units operational at the moment. These are called Haapaniemi 2 and Haapaniemi 3. The old Haapaniemi 1 plant is no more operational. Main fuel used in these boilers is peat, but the use of wood based biomass is increasing. (Kuopion Energia)

6.2 Haapaniemi 3

Haapaniemi 3 boiler is a Metso CYMIC^{TM} circulating fluidized bed boiler that has been operational from December 2011. It is designed to be able to combust a wide variety of fuels with minimal emissions. Plant has a thermal power of 80 MW and electric power of 40MW. 70% of fuel power is designed to be possible to receive from biofuel. The plant is an important factor in the plans of the city of Kuopio to reduce carbon dioxide emissions. Production of the Haapaniemi 3 plant replaced the production of old Haapaniemi 1 plant entirely. (Kuopion Ilmastopoliittinen Ohjelma 2009-2020)

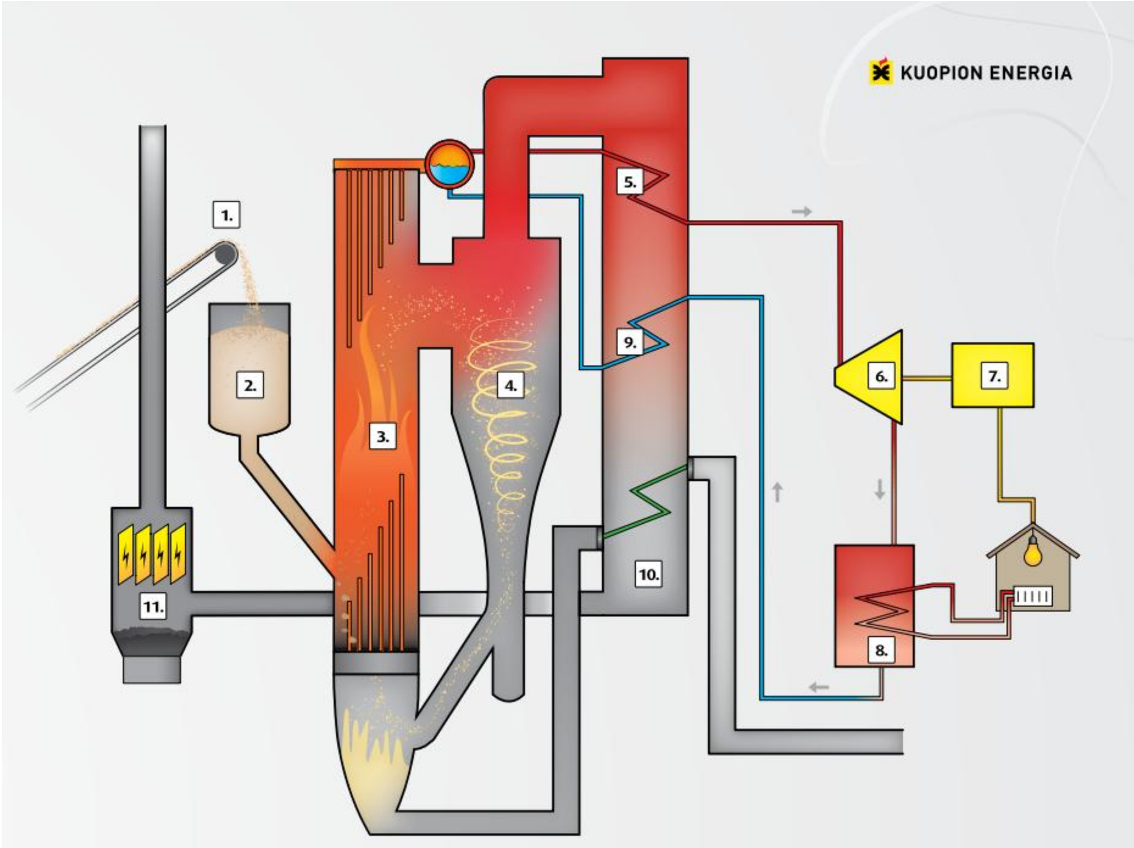

Figure 6.1: Haapaniemi 3 boiler plant (Kuopion Energia)

6.3 Metso DNA Corrosion Manager Application at Haapaniemi 3

Metso DNA Corrosion Manager at Kuopion Energia Haapaniemi 3 plant consists of superheater corrosion monitoring and optimal fuel diet control. Metso Corrored analyzer and a calculation application provide information for corrosion monitoring. Controls are implemented in Metso DNA environment. User interfaces are designed in Metso DNA Operate environment. A set of information reports are also included. (Nurmoranta et al. 2013)

6.3.1 On-line measurements and data transfer

Corrored analyzer is installed to the boiler. The analyzer provides on-line measurements for titrated chlorine and SO_4. Also S/Cl molar ratio signal is produced by the analyzer. Error and alarm signals are also delivered. Integration to Metso DNA environment is done with MODBUS protocol.

Floating average is calculated for titrated chlorine, titrated SO_4 and S/Cl molar ratio to be used in case on-line data is not available for some reason. Because the functionality of the analyzer may suffer when soot blowing is active near the analyzer, the analyzer is not measuring at the same time with soot blowing. (Nurmoranta et al. 2013)

6.3.2 Calculation application

The calculation application installed at Kuopion Energia Haapaniemi 3 plant is used to analyze the corrosivity of the furnace atmosphere based on on-line measurements from newly installed Corrored analyzer and other process measurements. Results of the calculation are corrosion risk index, corrosion rate, cumulative corrosion and Cl weight-% of the fuel. Calculations are designed in Metso DNA Historian Calculation environment using C# programming language.

Calculation uses the measurement averages of the calculation cycle. A validity check is done for every measurement value. Calculation is executed only when measurements from the calculation cycle are considered to be of good validity. Calculation results are saved in Metso DNA Historian database. Also measurements are saved in the same database.

Calculation uses formulas based on know-how of boiler manufacturer (Metso Power). Formulas are stored into SQL database with DNA Data application that was designed during this pilot project. (Nurmoranta et al. 2013)

6.3.3 Fuel diet control application

Corrosion control in Haapaniemi 3 plant is dealt with fuel diet control. Fuzzy logic is used in the application. Main idea is to control the amount of peat in the fuel mixture fed to the boiler. This way the S/Cl molar ratio is aimed to be steadied to a level, where corrosion risk is not significant. Because peat based control has a long response time, another control with a shorter response time is added. This additional control is done with coal feed control.

The logics take into account fuel storage statuses and try to prevent some fuel to run out. Possible conflicts with SO_2 emission restrictions are also taken into account with addition of lime feed control logics. Also fuel market statuses may be taken into account. This is done by choosing the more economical fuel, which is then treated as a primary fuel. Application checks also if the values from analyzer are realistic. If analyzer sends unrealistic values and those values are used, the calculation results would not be realistic. (Nurmoranta et al. 2013)

6.3.4 User interface

User interface in Haapaniemi 3 is based on the general design of DNA Corrosion Manager user interface. Some changes have been made to cover the plant specific details. Use of Finnish language is the most notable of these changes.

The main display module includes information of two superheaters, primary and secondary. This is because the highest corrosion risk may appear in both of these superheaters based on the different operative situations.

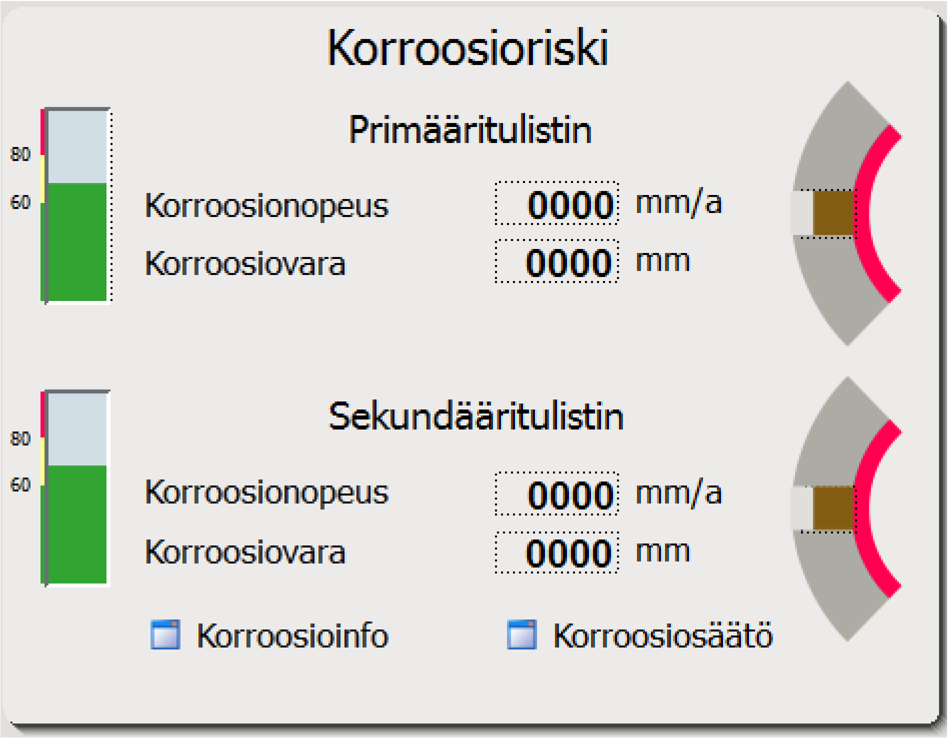

Figure 6.2: Layout of the main display module in Haapaniemi 3

Information display has information of only primary and secondary superheater. In this pilot project corrosion monitoring was not installed to cover loop seal superheater, because measurement techniques were not available. Measurements were not available also between first and second part of each superheater, so superheaters were treated as single units.

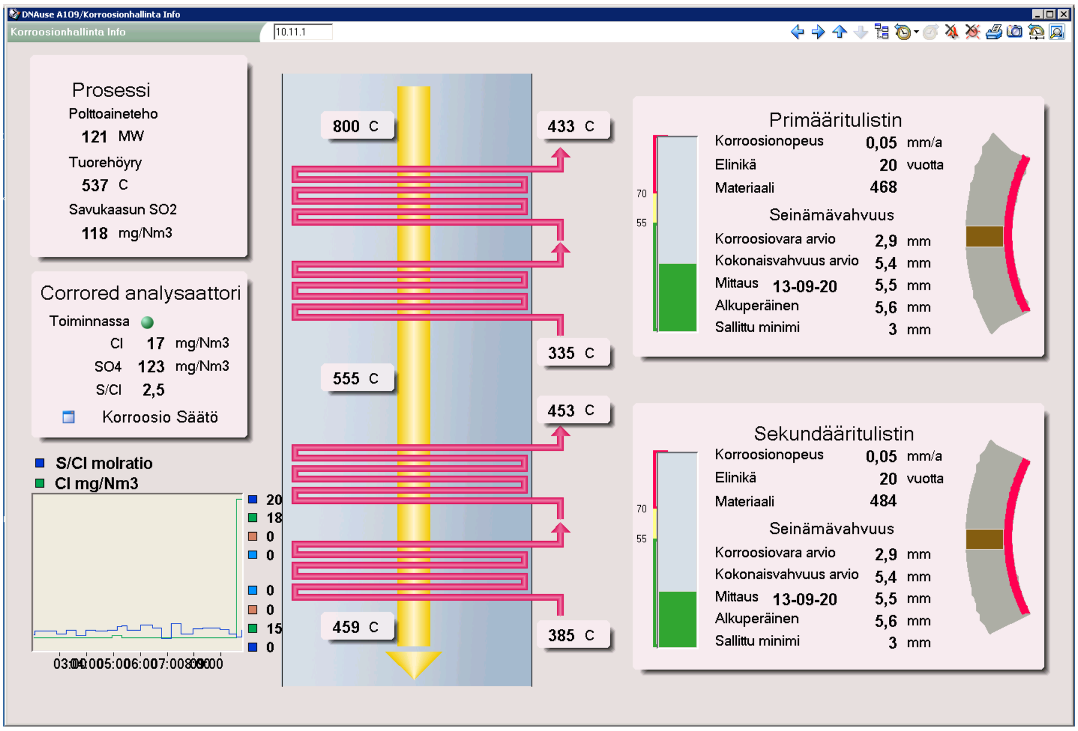

Figure 6.3: Information display in Haapaniemi 3

Control display does not have the features for additive feed control, because no such control was installed. Instead additional information could be added to the free space. The control features include peat/biofuel control, coal feed control and lime feed control. (Nurmoranta et al. 2013)

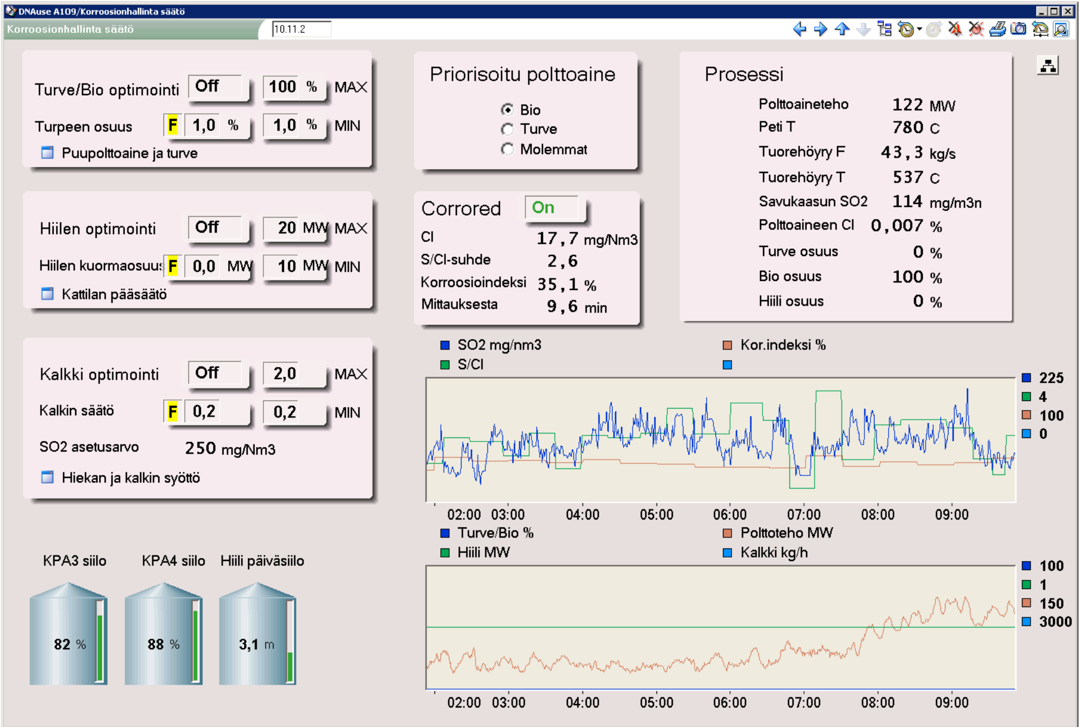

Figure 6.4: Control display in Haapaniemi 3

7 CONCLUSION

The goal of this thesis work was to develop control and info application to monitor and control superheater corrosion in boilers. The data from Metso Corrored analyzer is used in the application to provide customer with information about superheater corrosion and to control corrosiveness of the boiler atmosphere. A lot of focus is dedicated to the development of informative and user friendly user interface for this application. The development of the application included the pilot project to Kuopion Energia Haapaniemi 3 plant.

7.1 Corrosion in superheaters

Corrosion problems in superheaters are caused by different fuel chemistry in biofuels and recycled fuels compared to fossil fuels. The basic difference is that biofuels and recycled fuels have higher chlorine contents and lower sulfur contents compared to fossil fuels. This difference in fuel chemistry causes a formation of corrosive deposits in superheaters. Corrosiveness of these deposits increases also when temperature increases.

The solution to these problems is to affect the relation between sulfur and chlorine contents in the combustion. Other solution is to lower the temperature in the superheaters. The sulfur and chlorine contents may be controlled by adding more sulfur to the combustion by adding sulfur rich fuel to the combustion or by using a sulfur additive feed system. This control of sulfur to chlorine ratio needs a reliable and relatively quick measurement technology to analyze the sulfur to chlorine ratio. For this reason Metso has developed the Corrored analyzer that is used to measure the chlorine and sulfur content in flue gases.

7.2 Control and information application

To be able to benefit from the Corrored analyzer results, a control and information application was developed. This application is called Metso DNA Corrosion Manager. The application has four duties.

- Firstly the application gathers the data from the analyzer and saves it in a database where it is accessible for further analysis.
- Secondly the application analyzes the measurement data together with other process data by calculating figures for corrosion risk index [%], corrosion rate [mm/a] and cumulative corrosion [mm].

- Third duty of the application is to present these analyzed results to the operators or to the plant management in an informative manner.
- Final duty of the application is to control the corrosion with additive feed control, fuel diet control or by controlling the superheater temperature based on the analyze results.

7.3 User interface

In this thesis a large focus was given to the design process of the user interface of the application. General viewpoints and guidelines of user interface design were taken into account in the design process. The user interface of Metso DNA Corrosion Manager was designed to consist of two operator displays, one addition module to a main operator display and of a report for plant management.

The user interface design was done within limitations of Metso DNA platform. Some features were for this reason impossible to implement in the product. These features may be possible to implement in the future versions of the platform.

7.4 Pilot project

During this thesis work a pilot project was done to Kuopion Energia Haapaniemi 3 boiler plant. This project included the implementation of the Corrored analyzer to a circulating fluidized bed boiler made by Metso Power. The DNA Corrosion Manager application was implemented with fuel diet control, because the plant uses wood based biofuel and peat as main fuels and the plant has a possibility to use coal as a controlling fuel.

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